ABSTRACT : The largest problem facing human beings today is global warming. Every day, due to heavy consumption of petroleum and nuclear products, a huge amount of electricity is used. This electricity, in turn, fuels the global industry that produces cooling and warming systems for buildings, and this worrying reality has created a lot of biological disasters by adding pollution to our environment, including the increase of greenhouse gas etc.
Currently, seventy percent of developing countries are located in hot temperature climates. In addition to dealing with hot climate issues, these countries have other fundamental economic problems like: hunger, lack of conservation of agricultural products, food security and educational opportunities, in particular, having appropriate classroom space for children. .
In this research, several realistic, effective and operative solutions have been proposed through the use of economic passive cooling strategies of bioclimatic architecture in order to resolve some of the main problems facing many people who live in these areas. These economic solutions enriched from antique traditional methods of architecture, come from ancient Middle Eastern civilizations in conjunction with contemporary
bioclimatic architecture technologies and methodologies of passive cooling systems.

Dottorato di Ricerca
Pianificazione, Design, Tecnologia dell'Architettura

DOTTORANDO
Amir Imani

The Reappearance of Iranian Vernacular Architecture Using Natural Ventilation and Passive Cooling Strategies to Improve Conditions for Food Security and Education in Developing Countries with Hot Climates

Sapienza Università di Roma | Sapienza University of Rome | ciclo cycle XXX | nov. 2014 - Feb. 2019
Scuola di Dottorato in Ingegneria Civile e Architettura | Doctoral School in Civil Engineering and Architecture
Dipartimento di 'Pianificazione, Design, Tecnologia dell'Architettura' | 'Planning, Design, Technology of Architecture' Department

SAPIENZA
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PhD PLANNING, DESIGN, TECHNOLOGY OF ARCHITECTURE
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Curriculum PROGETTAZIONE TECNOLOGICA AMBIENTALE
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Copyright Statement

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I am also indebted to the Ministry of Culture and Higher Education of Iran, and the Cultural Heritage Office in the cities of Yazd, Ardakan, Meybod, Tabas, Kashan, Abarku and Tehran who assisted me in the preparation of all of the documents, photographs and maps of the various case studies.

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2018
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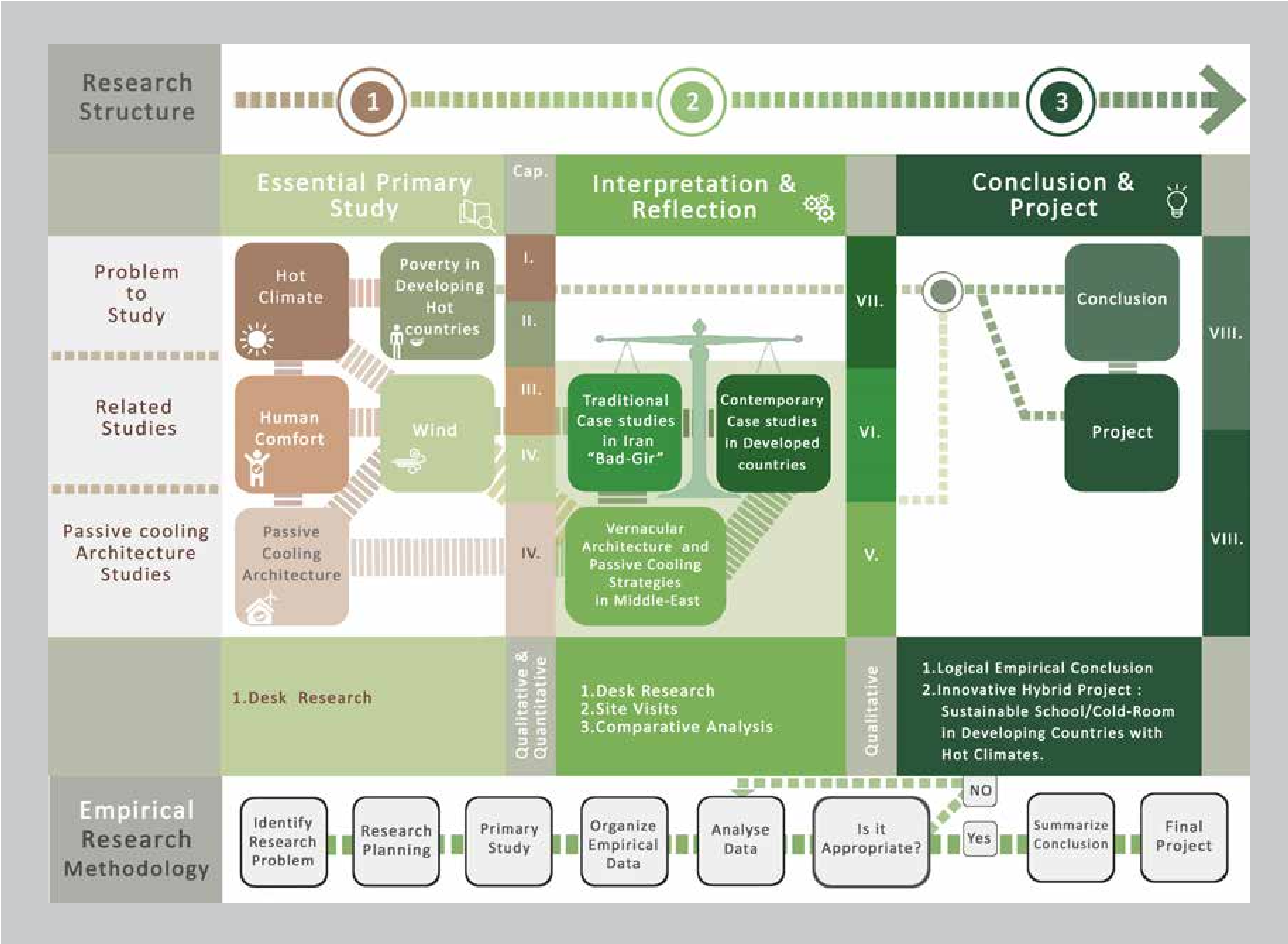


Research Structure
1
2
3
Essential Primary Study
Cap.
Interpretation & Reflection
Conclusion & Project
Problem to Study
Related Studies
Passive cooling Architecture Studies
Hot Climate
Poverty in Developing Hot countries
Human Comfort
Wind
Passive Cooling Architecture
I.
II.
III.
IV.
IV.
Traditional Case studies in Iran "Bad-Gir"
Contemporary Case studies in Developed countries
Vernacular Architecture and Passive Cooling Strategies in Middle-East
VII.
VI.
V.
Conclusion
Project
VIII.
VIII.
1.Desk Research
Qualitative & Quantitative
1.Desk Research
2.Site Visits
3.Comparative Analysis
Qualitative
1.Logical Empirical Conclusion
2.Innovative Hybrid Project : Sustainable School/Cold-Room in Developing Countries with Hot Climates.
Empirical Research Methodology
Identify Research Problem
Research Planning
Primary Study
Organize Empirical Data
Analyse Data
Is it Appropriate?
NO
Yes
Summarize Conclusion
Final Project

Structure and Methodology of research

The core of the structure and methodology of this research was built using Empirical research methods:

- A. Collecting essential information
- B. Interpretation and reflection
- C. Conclusion of result and project

The following methods were also used in this research, according to the various needs that arose.

- Historiography-interpretative
  Historiography-interpretative methods come from a word by word definitio ased on the title of this thesis: "Passive and natural cooling ventilation and evaporation systems (by Wind-tower/Bâd-gir) in historical buildings in th city of Yazd, Iran." We must conduct a deep exploration of the history and consider case studies to find the real roots of traditional Persian Bâd-girs (Wind-towers) and interpret their history.
- Inductive-deductive
  This method will be used when we are looking to discover results by comparing case studies and exploring similarities and differences among different cases in other countries.
- Scientific-applicative
  Digging into the scientific natural physics rules provided a new vision for arch tecture to create a new constructible innovation for its projects.
- Logical-dialectic
  After exploring all the materials that were obtained from the previous methods , the logical-dialectic method will be used to arrive at the final conclusion.

Introduction

This study reapplies traditional architecture methods of the Middle East, particularly in Iran, where the use of natural cooling systems by wind-towers in collaboration with other architectural elements, had created acceptable thermal comfort conditions for human life for many years, during times when there was no electricity or electrical cooling systems available, and where there were almost seven months of hot temperatures and at least four months of extremely hot temperatures during the year.
At the onset of the industrial revolution and modern architecture, the objectives and policies of capitalist governments and of the petroleum and energy industries were to promote the consumption of electricity and gas. As we now know, decades on this path have caused many remarkable ecological problems, including global warming, the melting of polar ice caps, the downfall of groundwater, massive increases in air and water pollution, natural disasters, lake droughts caused by the building of huge water digs for the production of electricity to name a few. In recent years, these disasters have made scientists and engineers more sensitive to these phenomena and have caused many governments from developed countries to initiate policies to try and change this direction in order to save our planet. Some of the most notable new international agreements include the implementation of the 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change.
The main challenge of this study was discovering how the ancient and vernacular architectural strategies of the Middle East that have been optimized by thousands of years of construction experience in extremely hot climates, can be applied to alleviate some of the most serious problems facing underdeveloped countries with hot climates today.
The final result of this research is presented as a new engineering and architectural product (prototype) based on science and historical principles, which could help to solve or reduce the problem of thermal discomfort in classroom spaces and increase the conservation time of locally grown agricultural products, thereby improving the area's "FOOD AND NUTRITION SECURITY." This architectural design could be implemented as a prefabricated product, with the possibility of being loaded onto local trailers and transported to the designated deprived regions. It could also be independent of the areas' local electrical energy, by using photovoltaic panels.
This dissertation's scientific content was collected from various books, Ph.D. theses, academic articles and essays along with some valid internet sites. My language skills

in English, Persian and Italian enriched this research greatly due to my possibility of using information from different publications and primary documents, in different places and in various original languages. In addition to personally conceiving the functioning of these Persian ventilation towers, I traveled to Iran twice on my own personal expense, and I surveyed the case studies in the cities of Yazd, Kashan, Abarkuh, Meybod, Taft and Tehran, observing, drawing and photographing all of the necessary data. I also conducted an interview with Dr. M.R. Oliya, former director of the Cultural Heritage organization of the city of Yazd.
There are many international organizations that are working to resolve some of the major problems facing developing countries, in particular, feeding the populations who are food insecure, agricultural development, peace building in conflict areas, and education: UNICEF, WFP, FAO, UNESCO etc. It is interesting to note that many of the people that have these needs are living in hot climate areas like: India, Northern and Sub-Saharan Africa, and the Middle-East. In this study, the principal objective is to provide some practical answers through sustainable architecture.
Recently, sustainable and near zero energy buildings are considered to be one of the important research branches for architects, that could help to save our planet more than ever before. However, it is noteworthy to know that hundreds of years ago in Middle Eastern countries like Iran, Iraq, Egypt, Pakistan, and Afghanistan – where extremely hot climates subsisted, their vernacular architecture carefully studied their surrounding environment and explored the forms behaviors. They had built wind-towers or wind-boxes in collaboration with other architecture elements like domes, water, apertures, vegetation etc. to create zero energy buildings where human comfort levels were close to the thermic comfort levels that we have introduced today.
This dissertation is divided into three general topics:

- **A.** The study of hot climate areas and the use of passive cooling systems and natural ventilation in architecture.Analysis of the social, economic and political issues related to poverty, in special concerning access to nutrition and education in developing countries in the world, and an introduction to the international organizations that play an important role in resolving these problems.
- **B.** Interpretation and reflection, create a complete picture of traditional passive cooling architecture strategies of Middle-East and compare data from case studies.
- **C.** Upon completion of analysis of the topics above, an innovative and complex architectural proposal will be presented. Through a passive architecture and natural ventilation path, two solutions can be applied towards the two underlying problems facing hot climate developing countries. The first solution will be thermal comfort in classrooms and the second will be the increased period of food security that will be accessed by local populations through the use of farm product storage in local underground refrigerated cellars.

In order to evaluate priorities, express specific objectives, and determine a suitable approach to researching this subject, this dissertation is divided into eight chapters.

- **I. Hot Climates:** This chapter will delve into the various climates of the world, scientifically analyze the definition and many typologies of hot climates, and where in the world they prevail. It will also introduce the diverse climates of Iran.

- **II. Effects of Hot Climate on Poverty and Food Security in Developing Countries and the Role of International Organizations and Sustainable Architecture:** After all of this research about architecture and climate is concluded; we now need to examine what are the main social problems prevalent in countries that are located in these hot climate areas of the world. If we look at the map of impoverished and developing countries and the map of hot climate areas in the world, we can see that around 70% of low-income countries are mostly located in hot areas. We can then try to understand, from the point of view of international humanitarian organizations, what major problems these countries face, and if sustainable architecture could provide any concrete solutions to these problems.

- **III. Wind:** This chapter will explain what wind is; how other factors such as: temperature, pressure, and natural elements like mountains, seas, lakes, and forests, could influence it. It will also provide a brief introduction of fluid-mechanics rules, which could be very useful for any architect or designer who wants to use natural ventilation and cooling systems in his or her projects.

- **IV. Thermal Comfort and Passive Architecture Technology in Hot Temperature Areas:** In this chapter, thermal comfort and its importance will be discussed. Throughout history, humans have survived in hot climates and they have been able to control their thermal condition through minimal efforts. The ways they applied architecture forms and behaviors to obtain a good thermal comfort in both their houses and their public spaces could be used as the best references for sustainable architecture in hot climates today. The chapter will then provide a description of the various passive cooling techniques, including heat reduction and prevention, thermal moderation, and natural cooling strategies. Several types of ventilation systems will also be analyzed. Hot-dry and hot-humid climates will be taken into account when looking at these strategies.

- **V. Vernacular and Traditional Architecture in Hot Climate Areas Across the Middle East:** The main objective of this chapter is to present a variety of distinctive traditional methods of architecture in the Middle East, digging through the history of wind-towers [and wind-boxes] to show their different typologies on the ancient Middle East map. It will divide them into two typologies, taking into account their position in different hot climates: A) Hot-humid and B) Hot-dry. It will then explain what functional differences they have during both day and night. Furthermore, it will offer a practical classification of them based on effective items, which have remarkable influence on their function, for example, height and number of their cap-openings (head-opening, top-opening).

- **VI. Compound Analysis of Iranian Wind-Boxes & Wind-Towers in Cooperation with Other Architectural Elements (Case Studies A):** The aim of this chapter is to give more focus on passive cooling architecture in the hot climate parts of Iran, and it will demonstrate the advanced representative architecture of the ancient world. In this research for the first time, a new classification for Iranian wind-towers will be presented, based on the different functions of wind-towers, its position in the plan, and its interaction with other operative architectural elements such as: courtyards, vegetation, fountains, cupolas, windows and underground floors. Finally, an explanation of all the benefits and defects of wind-towers will be provided. It should be noted that all of the data, information, architecture plans and photographs in this chapter were personally collected and produced from Iran.

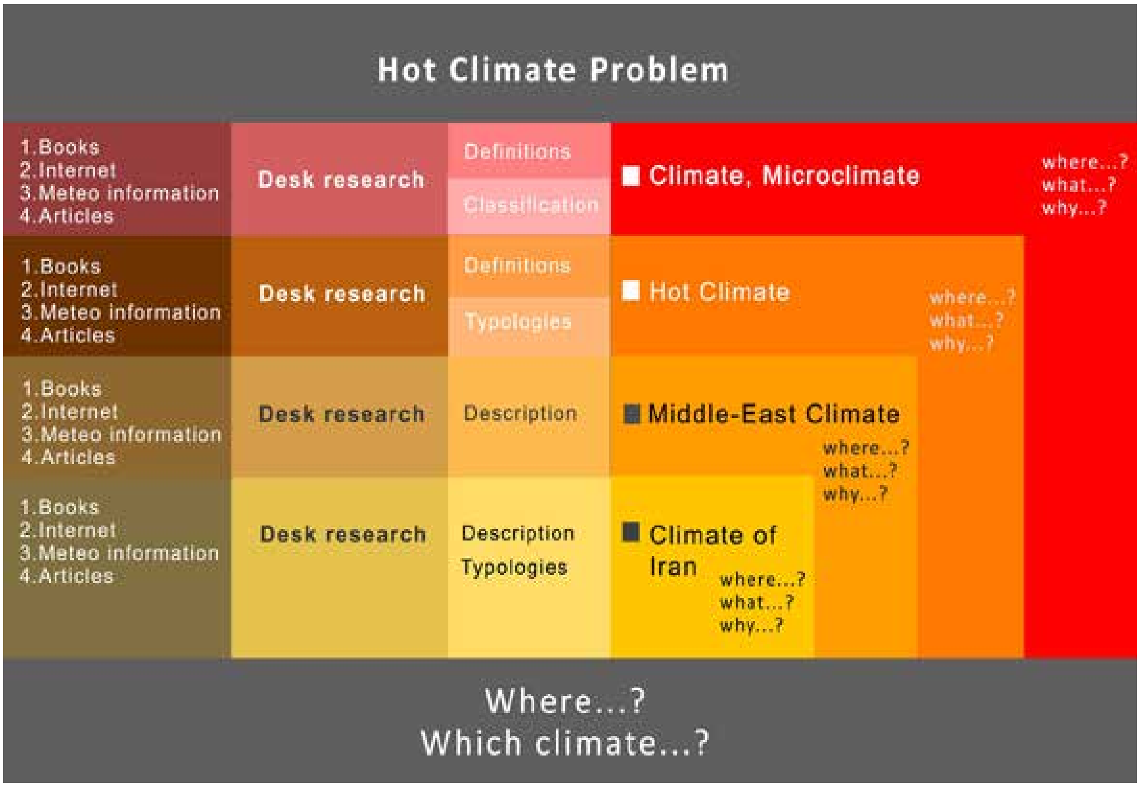
- **VII. Contemporary Passive Cooling Strategies in Architecture (Focused on Natural Ventilation) (Case Studies B):** In previous chapters, we have studied natural ventilation within the ancient architecture of the Middle East. The goal of this chapter is to discover how new architecture technology and innovation, in contemporary architecture, have been used in natural ventilation and passive cooling systems. At the end of this part, a presentation will be provided of all of the various new opportunities that could be worthy of passive ventilation in architecture as well as their obstacles.

- **VIII. Practical Conclusion – Hope-Box +Wind-Tower (HB+WT):** Through logical questioning, we will try to understand what kinds of architecture and which functions could be most suitable in the construction of buildings in these hot climate areas. The final part explains development of the innovative idea of HBWT, which will be composed of two prefabricated boxes, one on top of the other with two wind-towers, two cupolas and photovoltaic panels on the roof. The ground floor will be used as two classrooms with a passive ventilation cooling system and underground boxes will be used as a storage space to conserve and protect agricultural products (crops and animal products). The ideal temperature to conserve these products is 7°C to 10°C and it is interesting to note that underground floors usually have a fixed temperature of around 20 °C , and this was the place where traditionally, people living in hot climates used to escape high temperatures and conserve food for longer periods of time.

PART I

Identify the Problems and Define the Scientific Structure

CHAPTER 1 Hot Climates



Hot Climate Problem
1.Books
2.Internet
3.Meteo information
4.Articles
Desk research
Definitions
Classification
Climate, Microclimate
where...?
what...?
why...?
1.Books
2.Internet
3.Meteo information
4.Articles
Desk research
Definitions
Typologies
Hot Climate
where...?
what...?
why...?
1.Books
2.Internet
3.Meteo information
4.Articles
Desk research
Description
Middle-East Climate
where...?
what...?
why...?
1.Books
2.Internet
3.Meteo information
4.Articles
Desk research
Description
Typologies
Climate of Iran
where...?
what...?
why...?
Where...?
Which climate...?

1.1 Objective

- Present a factual image of climates on a world map
- Define typology of hot climates in the world
- Understand the different characteristics of typologies of hot climate areas
- Introduce the climates of Iran
- Explain the influence of climate on energy consumption

1.2 Climate Definition

Climate is the statistics of weather over long periods of time. [1] It is measured by assessing the patterns of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time.

Climate (from Ancient Greek klima, meaning inclination) is commonly defined as the weather averaged over a long period. [2] The standard averaging period is 30 years, [3] but other periods may be used depending on the purpose. Climate also includes statistics other than the average, such as the magnitudes of day-to-day or year-to-year variations. The Intergovernmental Panel on Climate Change (IPCC) 2001 glossary definition is as follows:

“Climate in a narrow sense is usually defined as the ‘average weather,’ or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.” [4]

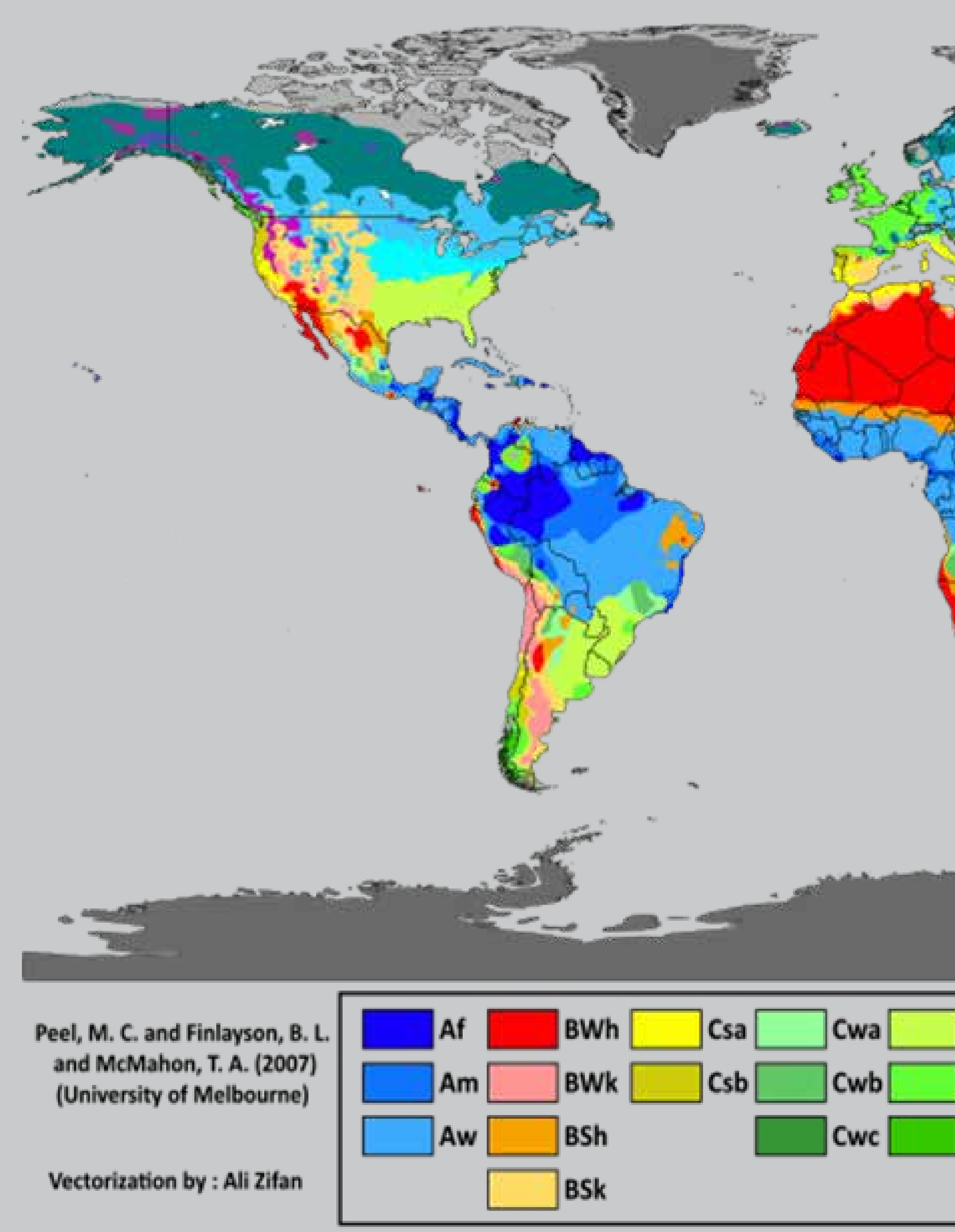
Climate differs from weather, in that weather only describes the short-term conditions of these variables in a given region. A region’s climate is generated by the climate system, which has five components: atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere. [5] The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents.

1.3 Climate Classification

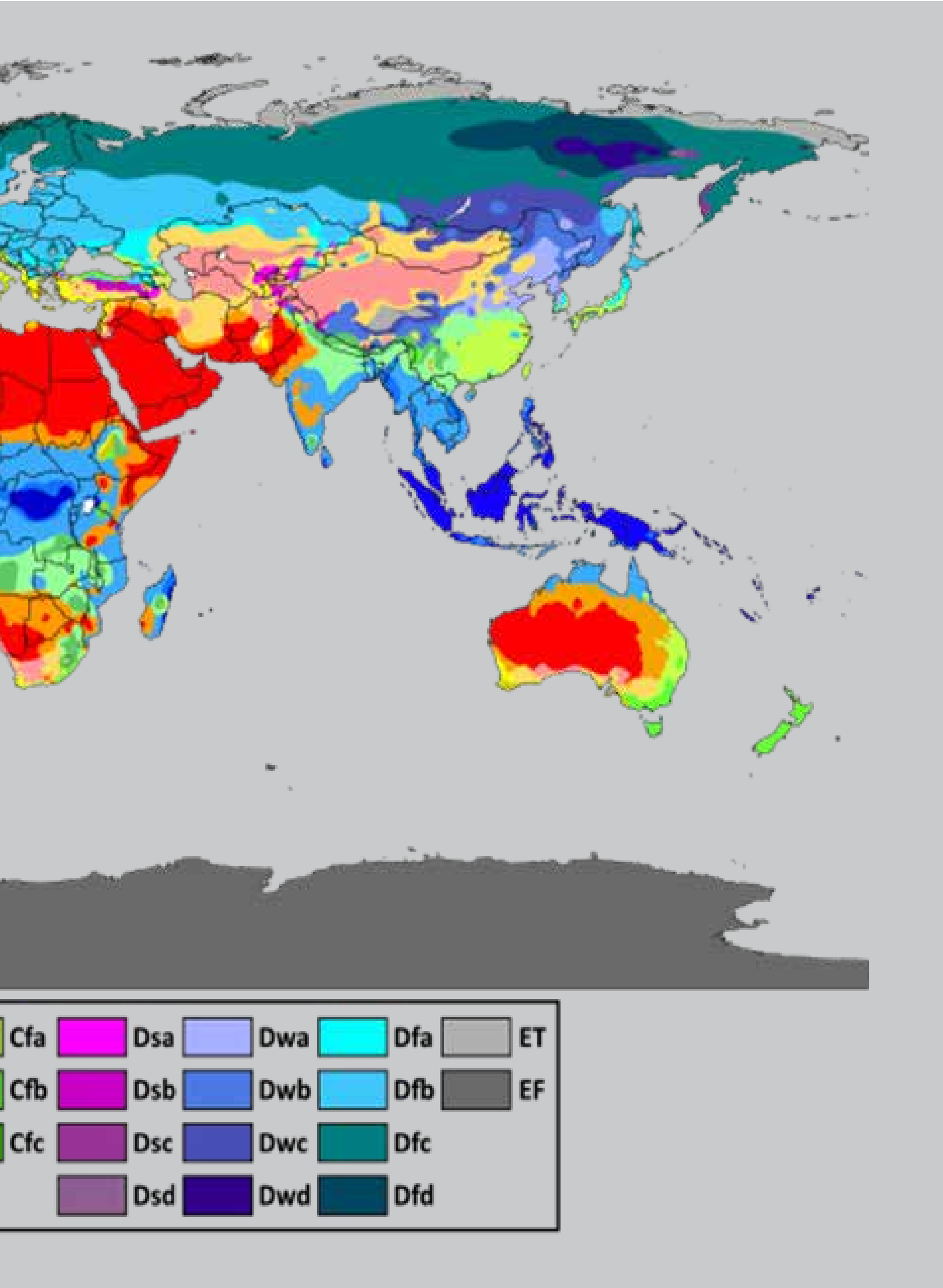
Climates can be classified according to the average and the typical ranges of different variables, most commonly, temperature and precipitation. The most commonly used classification scheme was the Köppen [Fig-1] climate classification. The Thornthwaite system, [6] in use since 1948, incorporates evapotranspiration along with temperature and precipitation information and is used in studying biological diversity and how climate change affects it.

There are many different types of classification for climate. The simplest classification is that involving air masses. The Bergeron classification is the most widely accepted form of air mass classification. [7]

8.



[Fig-1] Köppen Classification



Cfa
Cfb
Cfc
Dsa
Dsb
Dsc
Dsd
Dwa
Dwb
Dwc
Dwd
Dfa
Dfb
Dfc
Dfd
ET
EF

1.3.1 The Köppen Classification

This classification [Tab-1] depends on average monthly values of temperature and precipitation.
The Köppen climate classification scheme divides climates into five main climate groups: [7]

- A (tropical)
- B (dry)
- C (temperate)
- D (continental)
- E (polar)
- The second letter indicates the seasonal precipitation type.

The third letter indicates the level of heat. [8]
Five primary classifications can be further divided into secondary classifications such as rainforest, monsoon, tropical savannah, humid subtropical, humid continental, oceanic climate, Mediterranean climate, desert, steppe, subarctic climate, tundra, and polar ice cap. [Tab-1]

1.3.1.1 Group A: Tropical (Mega-Thermal) Climates

This type of climate has every month of the year with an average temperature of 18 °C (64.4 °F) or higher, with significant precipitation.

Af = Tropical rainforest climate; average precipitation of at least 60 mm (2.4 in) in every month.

Rainforests are characterized by high rainfall, with definitions setting minimum normal annual rainfall between 1,750 mm (69 in) and 2,000 mm (79 in). Mean monthly temperatures exceed 18 °C (64 °F) during all months of the year. [9]
Am = Tropical monsoon climate; driest month (which nearly always occurs at or soon after the "winter" solstice for that side of the Equator) with precipitation less than 60 mm (2.4 in), but more than 4% of the total annual precipitation.
A **monsoon** is a seasonal prevailing wind that lasts for several months, ushering in a region's rainy season.[10] Regions within North America, South America, Sub-Saharan Africa, Australia and

East Asia are monsoon regimes. [11]
Aw* or *As = Tropical wet and dry or savannah climate; with the driest month having precipitation less than 60 mm (2.4 in) and less than 4% of the total annual precipitation.
A tropical savannah is a grassland biome located in semi-arid to semi-humid climate regions of subtropical and tropical latitudes, with average temperatures remaining at or above 18 °C (64 °F) year round and rainfall between 750 mm (30 in) and 1,270 mm (50 in) a year. They are widespread in Africa, and are found in India, the northern parts of South America, Malaysia, and Australia. [12]

1.3.1.2 Group B: Dry (Arid and Semi-Arid) Climates

This type of climate is defined by little precipitation. Multip
ly the average annual temperature in Celsius by 20, then add:
(a) 280 if 70% or more of the total precipitation is in the spring and summer months (April–September in the Northern Hemisphere, or October–March in the Southern), or
(b) 140 if 30% – 70% of the total precipitation is received during the spring and summer, or
(c) 0 if less than 30% of the total precipitation is received during the spring and summer.
If the annual precipitation is less than 50% of this threshold, the classification is **BW** (arid: desert climate); if it is in the range of 50% – 100% of the threshold, the classification is **BS** (semi-arid: steppe climate).
A third letter can be included to indicate temperature. Originally, **h** signified low-latitude climate (average annual temperature above 18 °C (64.4 °F)) while **k** signified middle-latitude climate (average annual temperature below 18 °C), but the more common practice today, especially in the United States, is to use **h** to mean the coldest month has an average temperature above 0 °C (32 °F) (or −3 °C (27 °F)), with **k** denoting that at least one month's averages below 0 °C (or −3 °C (27 °F)). The **n** is used to denote a climate characterized by frequent fog.

- **BWh** = Hot desert climate
- **BWk** = Cold desert climate
- **BWn** = Desert climate with frequent fog
- **BSh** = Hot semi-arid climate
- **BSk** = Cold semi-arid climate
- **BSn** = Semi-arid climate with frequent fog

1.3.1.3 Group C: Temperate (Mesodermal) Climates

This type of climate has the coldest month averaging between 0 °C (32 °F) (or −3 °C (27 °F)) and 18 °C (64.4 °F) and at least one month averaging above 10 °C (50 °F).

- **Cfa** = Humid subtropical climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled). No dry months in the summer.

- **Cfb** =_Temperate oceanic climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

- **Cfc** = Subpolar oceanic climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)) and 1 – 3 months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

- **Cwa** = Monsoon-influenced humid subtropical climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- **Cwb** = Subtropical highland climate or Monsoon-influenced temperate oceanic climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation received in the warmest six months).

- **Cwc** = Cold subtropical highland climate or Monsoon-influenced subpolar oceanic climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)) and 1 – 3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- **Csa** = Hot-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer and driest month of summer receives less than 30 mm (1.2 in).

- **Csb** = Warm-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer and driest month of summer receives less than 30 mm (1.2 in).

- **Csc** = Cool-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F) (or −3 °C (27 °F)) and 1 – 3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

The Mediterranean climate regime resembles the climate of the lands in the Mediterranean Basin, parts of western North America, parts of Western and South Australia, in southwestern South Africa and in parts of central Chile. The climate is characterized by hot, dry summers and cool, wet winters. [15]
The humid subtropical climate zone where winter rainfall (and sometimes snowfall) is associated with large storms that the west-

erlies steer from west to east. Most summer rainfall occurs during thunderstorms and from occasional tropical cyclones. [16] Humid subtropical climates lie on the east side of continents, roughly between latitudes 20° and 40° degrees away from the Equator. [17]

1.3.1.4 Group D: Continental (Microthermal) Climates

- This type of climate has at least one month averaging below 0 °C (32 °F) (or −3 °C (27 °F)) and at least one month averaging above 10 °C (50 °F).

- <u>Dfa</u> = Hot–summer humid continental climate; coldest month averaging below −0 °C (32 °F) (or −3 °C (27 °F)), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

- <u>Dfb</u> = Warm-summer humid continental climate; coldest month averaging below −0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

- <u>Dfc</u> = Subarctic climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)) and 1 – 3 months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

- <u>Dfd</u> = Extremely cold subarctic climate; coldest month averaging below −38 °C (−36.4 °F) and 1 – 3 months averaging above 10 °C (50 °F). No significant precipitation difference seasons (neither abovementioned set of conditions fulfilled).

- <u>Dwa</u> = Monsoon-influenced hot-summer humid continental climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)), at least one month's average temperature above 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- Dwb = Monsoon-influenced warm-summer humid continental climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- Dwc = Monsoon-influenced subarctic climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)) and 1 – 3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- Dwd = Monsoon-influenced extremely cold subarctic climate; coldest month averaging below −38 °C (−36.4 °F) and 1 – 3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- Dsa = Mediterranean-influenced hot-summer humid continental climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)), average temperature of the warmest month above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At

- Dsb = Mediterranean-influenced warm-summer humid continental climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)), average temperature of the warmest month below 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

- Dsc = subarctic climate; coldest month averaging below 0 °C (32 °F) (or −3 °C (27 °F)) and 1–3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer and driest month of summer receives less than 30 mm (1.2 in).

- Dsd = extremely cold, subarctic climate; coldest month averaging below −38 °C (−36.4 °F) and 1 – 3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer and driest month of summer receives less than 30 mm (1.2 in).

A subarctic climate has little precipitation, [18] and monthly temperatures which are above 10 °C (50 °F) for one to three months of the year, with permafrost in large parts of the area due to the cold winters. Winters within subarctic climates usually include up to six months of temperatures averaging below 0 °C (32 °F). [19]
Humid continental climate: A humid continental climate is marked by variable weather patterns and a large seasonal temperature variance. Places with more than three months of average daily temperatures above 10 °C (50 °F) and a coldest month temperature below −3 °C (27 °F) and which do not meet the criteria for an arid or semiarid climate, are classified as continental. [20]

1.3.1.5 Group E: Polar and Alpine (Mountain) Climates

This type of climate has an average temperature below 10 °C (50 °F) every month of the year.

- ET = Tundra climate; average temperature of warmest month between 0 °C (32 °F) (or −3 °C (27 °F)) and 10 °C (50 °F).
- EF = Ice cap climate; eternal winter, with all 12 months of the year with average temperatures below 0 °C (32 °F) (or −3 °C (27 °F)).

Tundra occurs in the far Northern Hemisphere, north of the taiga belt, including vast areas of northern Russia and Canada. [21]
A polar ice cap, or polar ice sheet, is a high-latitude region of a planet or moon that is covered in ice. Ice caps form because high-latitude regions receive less energy as solar radiation from the sun than equatorial regions, resulting in lower surface temperatures. [22]

v

1st	2nd	3rd
A (Tropical)	f (Rainforest)	
	m (Monsoon)	
	w (Savanna, Wet)	
	s (Savanna, Dry)	
B (Arid)	W (Desert)	
	S (Steppe)	
		h (Hot)
		k (Cold)
		n (With frequent fog)[10]
C (Temperate)	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
D (Cold (continental))	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
		d (Very cold winter)
E (Polar)	T (Tundra)	
	F (Eternal winter (ice cap))	

[Tab-1] Köppen Classification Schedule

1.4 Microclimate

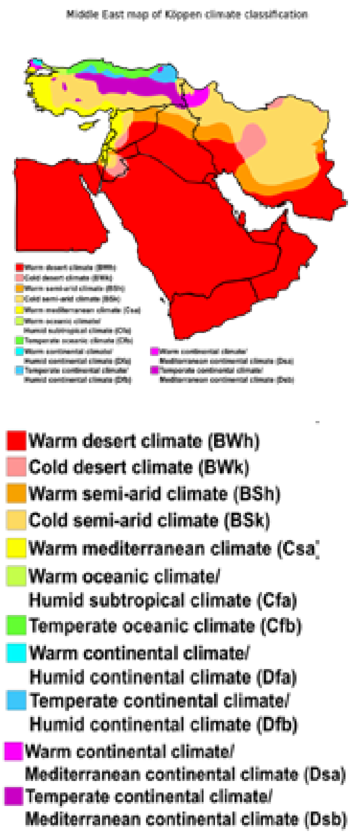
A microclimate is a local set of atmospheric conditions that differ from those in the surrounding areas, often with a slight difference but sometimes with a substantial one. The term may refer to areas as small as a few square meters or square feet (for example a garden bed or a cave) or as large as many square kilometers or square miles. Because climate is statistical, which implies spatial and temporal variation of the mean values of the describing parameters, within a region there can occur and persist over time sets.
The terminology "micro-climate" first appeared in the 1950s in publications such as Climates in Miniature: A Study of Micro-Climate Environment (Thomas Bedford Franklin, 1955) as statistically distinct conditions, that is, microclimates. Microclimates can be found in most places.
In an urban area, tall buildings create their own microclimate, both by overshadowing large areas and by channeling strong winds to ground level. Wind effects around tall buildings are assessed as part of a microclimate study.

1.5 Climate of Study (Middle East)

Initial parts of this research are located in Iran, Arab countries around the Persian Gulf and Egypt, in other words in the Middle East. [Fig-2] The objective is to discover passive ventilation systems in the architecture located in these areas.
The Middle East has a mostly hot and arid climate. Some major rivers in the area irrigate the surrounding land, which supports agriculture in certain areas, such as the Nile Delta in Egypt, and between the Tigris and Euphrates rivers in Iraq, commonly known as the Fertile Crescent in Mesopotamia.

“The birthplace of three major religions and civilization, the Middle East has always been a dry place. The basic climate of the Middle East is hot and dry, although winters are mild with little rain. To the north of the desert are the great steppes. This area has extremes in temperatures and has rain in winter and spring. The rest of the area has rainfall between March and November and sometimes floods from March to May. Summers are long and hot and winters are mild and wet along the Mediterranean coast. The coastal areas are humid but have a steady breeze to compensate. Across the Middle East, summer temperatures are usually around 29 °C (85 °F), but often rise above 38 °C (100 °F). In Baghdad, the record high is 49 °C (120 °F); in Basra, 51 °C 124 °F, the highest temperatures recorded in any major Middle Eastern city. In the Saudi desert, however, temperatures over 49 °C (120 °F) are common. Most storms crossing the Middle East become dust- or sandstorms when strong winds whip the dry desert surface; as many as 38 occur annually.” [23]

Most parts of the Middle East have warm desert climates (BWh) [Fig-2] in this order (BSh), (Bsk), (BWk) etc. Therefore, all of the information that will be presented in the next chapters could be useful for any (BWh), (BWn), or (BSh) areas, where there are at least five extremely hot months in the year..



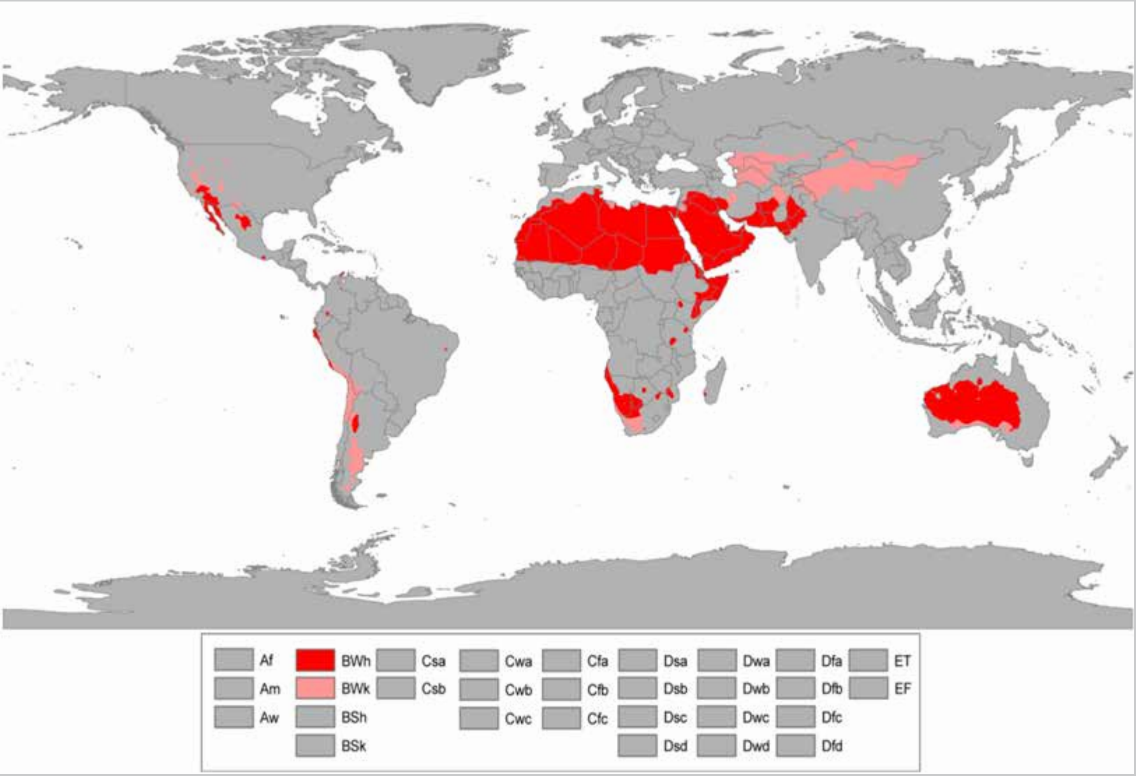
[Fig-2] Köppen Middle-East Climate Classification

1.6 Desert Climate BWh, BWk

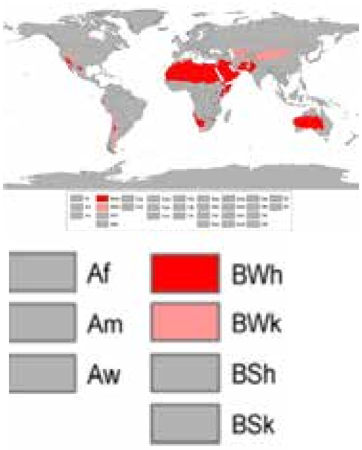
The Desert climate (in the Köppen climate classification BWh and BWk, [Fig-3] sometimes also BWn), also known as an arid climate, is a climate in which precipitation is too low to sustain any vegetation at all, or at most, a very scanty shrub, and does not meet the criteria to be classified as a polar climate.
An area that features this climate usually experiences from 25 to 200 mm (7.87 in) per year of precipitation [24] and in some years, may experience no precipitation at all. Averages may be even less, such as in the U.S. and Chile, where normal precipitation stands at around 1 mm per year. In some instances, an area may experience more than 200 mm of precipitation annually but is considered a desert climate because the region loses more water via evapotranspiration than falls as precipitation (Tucson, Arizona USA and Alice Springs, Northern Territory Australia are examples of this).
There are usually two or three variations of a desert climate: a hot desert climate (BWh), a cold desert climate (BWk) and, sometimes, a mild desert climate (BWh/BWn). Furthermore, to delineate "hot desert climates" from "cold desert climates," there are three widely used isotherms: either a mean annual temperature of 18 °C (which is the most accurate and most commonly used), or a mean temperature of 0 °C or −3 °C in the coldest month, so that a location with a "BW" type climate with the appropriate temperature above whichever isotherm is being used is classified as "hot arid" (BWh), and a location with the appropriate temperature below the given isotherm is classified as "cold arid."
A location has an arid climate, and the precipitation threshold is determined. The precipitation threshold (in millimeters) involves first multiplying the average annual temperature in °C by 20, then adding 280 if 70% or more of the total precipitation is in the high-sun half of the year (April through September in the Northern Hemisphere, or October through March in the Southern), or 140 if 30 – 70% of the total precipitation is received during the applicable period, or 0 if less than 30% of the total precipitation is so received. If the area's annual precipitation is less than half the threshold, it is classified as a BW (desert climate). [25]
Around 5.9 million mi^2 (near 153 million km^2) is the surface area of the hot deserts in the world. [Tab-2] [26]

Major Deserts of the World			
Name	Type of Desert	Surface Area	Location
Antarctic	Polar	5.5 million mi²	Antarctica
Arctic	Polar	5.4 million mi²	Alaska, Canada, Greenland, Iceland, Norway, Sweden, Finland, Russia
Sahara	Subtropical	3.5 million mi²	Northern Africa
Arabian	Subtropical	1 million mi²	Arabian Peninsula
Gobi	Cold Winter	500,000 mi²	China and Mongolia
Patagonian	Cold Winter	260,000 mi²	Argentina
Great Victoria	Subtropical	250,000 mi²	Australia
Kalahari	Subtropical	220,000 mi²	South Africa, Botswana, Namibia
Great Basin	Cold Winter	190,000 mi²	United States
Syrian	Subtropical	190,000 mi²	Syria, Iraq, Jordan, Saudi Arabia
Chihuahuan	Subtropical	175,000 mi²	Mexico
Great Sandy	Subtropical	150,000 mi²	Australia
Kara-Kum	Cold Winter	135,000 mi²	Uzbekistan, Turkmenistan
Colorado Plateau	Cold Winter	130,000 mi²	United States
Gibson	Subtropical	120,000 mi²	Australia
Sonoran	Subtropical	120,000 mi²	United States, Mexico
Kyzyl-Kum	Cold Winter	115,000 mi²	Uzbekistan, Turkmenistan, Kazakhstan
Taklamakan	Cold Winter	105,000 mi²	China
Iranian	Cold Winter	100,000 mi²	Iran
Thar	Subtropical	75,000 mi²	India, Pakistan
Simpson	Subtropical	56,000 mi²	Australia
Mojave	Subtropical	54,000 mi²	United States
Atacama	Cool Coastal	54,000 mi²	Chile
Namib	Cool Coastal	13,000 mi²	Angola, Namibia, South Africa

[Tab-2] Main Deserts in the World



[Fig-3] Desert Climate



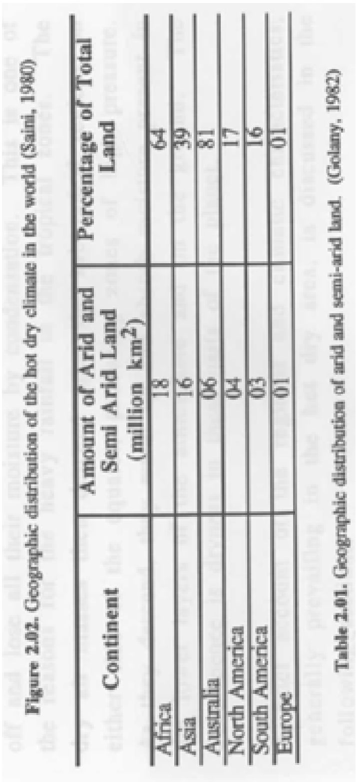


Figure 2.02. Geographic distribution of the hot dry climate in the world (Saini, 1980)

Continent	Amount of Arid and Semi Arid Land (million km^2)	Percentage of Total Land
Africa	18	64
Asia	16	39
Australia	06	81
North America	04	17
South America	03	16
Europe	01	01

Table 2.01. Geographic distribution of arid and semi-arid land. (Golany, 1982)

[Tab-3] BWh Amount of Arid and Semi Arid Land on the Continents

1.6.1 Desert Climate BWh

Hot desert climates (BWh) are typically found under the subtropical ridge where there is largely unbroken sunshine for the whole year due to the stable descending air and high pressure aloft. These areas are located between 30 ° South and 30 ° North latitude, under the subtropical latitudes called the horse latitudes. Hot desert climates are generally hot, sunny and dry all year round. They rise at higher latitude in the south western United States in the sheltered regions warmed up in winters by the Pacific Ocean, enabling searing summer temperatures in the Death Valley basin at 36° latitude. Hot desert climates also reach similar latitudes in the Middle East, North Africa and coastal southeastern areas of Spain.
Hot dry climate can be found in the subtropical regions of Africa, central and western Asia, in the west of North and South America, and in central and Western Australia. Africa contains the largest portion of arid land with a total of 18 million Km2 amounting to 64% of its total area. Europe on other hand, contains only one million Km2 of arid land amounting to approximately 1 % of its total area. Australia by percentage, is the most arid continent in the world. All the hot dry regions occupy over one-fifth of the earth's surface and comprise more than one-third of the whole world's population. [Tab-3] The hot dry climate prevails between 15°– 35° north and south latitudes.
Hot desert climates usually feature hot, sometimes exceptionally hot, periods of the year. In many locations featuring a hot desert climate, maximum temperatures of over 40 °C (104 °F) are not uncommon in summer and can soar to over 45 °C (113 °F) in the hottest regions. The world absolute heat records, over 50 °C (122 °F), are generally in the hot deserts, where the heat potential is the highest on the planet. Some desert locations consistently experience very high temperatures all year long, even during wintertime. These locations feature some of the highest annual average temperatures recorded on Earth, averages which can exceed 30 °C (86 °F). This last feature is seen in sections of Africa and Arabia. During colder periods of the year, nighttime temperatures can drop to freezing or below due to the exceptional radiation loss under the clear skies. However, very rarely do temperatures drop far below freezing.
Hot desert climates can be found in the deserts of North Africa, such as the wide Sahara Desert; the Libyan or Nubian Desert; deserts in

the Horn of Africa such as the Danakil Desert or the Grand Bara Desert; deserts of Southern Africa, such as the Namib Desert or the Kalahari Desert; deserts of the Middle East, such as the Arabian Desert, the Syrian Desert or the Lut Desert; deserts of South Asia, such as Dasht-e Kavir, [Fig-4] Dasht-e Loot, or the Thar Desert of India and Pakistan; deserts of the United States and Mexico such as the Mojave Desert, the Sonoran Desert or the Chihuahuan Desert; deserts of Australia such as the Simpson Desert or the Great Victoria Desert and many other regions. A small handful of locations in Europe has a hot desert climate; the Cabo de Gata-Níjar Natural Park in Almería and a small area in the southwest of Murcia and Alicante, Spain. [27] Additionally, parts of the Canary Islands (particularly Fuerteventura and Lanzarote) has a hot desert climate. [28]

[Fig-4] Dasht-e-Kavir, Largest Desert in Iran Near the City of Yazd

1.6.1.1 Sky Condition and Solar Heat Radiation

“Unlike other climates, where convection heat transfer phenomena are dominated, radiation is the most powerful in arid zones. Since clouds form so rarely and the moisture content of the air is often very low, the solar radiation strikes the arid land directly. Up to 95% of the solar radiation may reach the ground, especially in open desert lands. Direct solar radiation, therefore, is intense on horizontal surfaces (up to 800 or 900 W/ m 2) and is further increased by reflection from light colored terrain. Hot dry regions receive a great amount of solar radiation during the days but tend to a cool down rapidly after sunset. The absence of clouds and the low level of atmospheric moisture make it possible for approximately 95% of the heat stored in the terrain to be emitted by radiation into the higher layer of the atmosphere. For the greater part of the year, the sky is cloudless, but dust, haze and storms are frequent. These are caused by the intensive heating of the air near the ground, occurring mainly in the afternoon. [29] After a dust storm, larger particles will settle down, but a mass of extremely light weight particles form a dry fog and remain in the atmosphere for a long period of time, limiting visibility in the affected area.” [30]

1.6.2 Cold Desert Climates (BWk)

This climate usually features hot (or warm in a few instances), dry summers, though summers are not typically as hot as hot desert climates. Unlike hot desert climates, cold desert climates tend to feature cold, dry winters. [31] Snow tends to be rare in regions with this climate. The Gobi Desert [Fig-5] in Mongolia is a classic example for cold deserts. Though hot in the summer, it shares the very cold winters of the rest of Central Asia. Cold desert climates are typically found at higher altitudes than hot desert climates and are usually drier than hot desert climates.

[Fig-5] Gobi Desert, in Northern China and Southern Mongolia

Cold desert climates are typically located in temperate zones, usually in the rain shadow of high mountains, which restrict precipitation from the westerly winds. An example of this is the Patagonian Desert in Argentina, bounded by the Andes to its west. In the case of Central Asia, mountains restrict precipitation from the monsoons. The Kyzyl Kum, Taklamakan and Katpana Desert deserts of Central Asia and the drier portions of the Great Basin Desert of the western United States are other major examples of BWk climates. The Ladakh region, and Leh city in the Great Himalayas in India, also have a cold desert climate. This is also found in Europe, primarily in Bardenas Reales near Tudela, Navarre and high-altitude parts of the Tabernas Desert in Almería, Spain.

Arctic and Antarctic regions also receive very little precipitation during the year, owing to the exceptionally cold dry air. However, both of them are generally classified as having polar climates because they have average summer temperatures below 10 °C (50 °F).

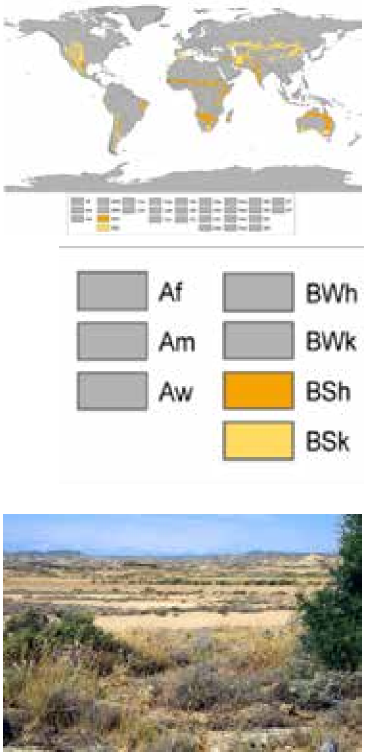
Hot deserts have extreme temperatures. Most of these areas are the hottest, sunniest and driest on the planet. They have a constant level of high pressure and have almost a permanent void of low-pressure systems, and atmospheric disturbances, sinking air motion; dry atmosphere near the surface; and there is an intensified exposure to the sun where solar angles are always high.

1.7 Semi-Arid

A semi-arid [Fig-6] climate or steppe climate is the climate of a region that receives prvecipitation below potential evapotranspiration, but not as low as a desert climate. There are different kinds of semi-arid climates, depending on variables such as temperature, and they give rise to different biomes. Defining attributes of semi-arid climates, a more precise definition is given by the Köppen climate classification, which treats steppe climates (BSk and BSh) as intermediates between desert climates (BW) and humid climates in ecological characteristics and agricultural potential. Semi-arid climates tend to support short or scrubby vegetation and are usually dominated by either grasses or shrubs.

To determine if a location has a semi-arid climate, the precipitation threshold must first be determined. Finding the precipitation threshold (in millimeters) involves first multiplying the average annual temperature in °C by 20, then adding 280 if 70% or more of the total precipitation is in the high-sun half of the year (April through September in the Northern temperate zone, or October through March in the Southern), or 140 if 30% – 70% of the total precipitation is received during the applicable period, or 0 if less than 30% of the total precipitation is received. If the area's annual precipitation is less than the threshold but more than half the threshold, it is classified as a BS (steppe climate). [32] Furthermore, to delineate "hot semi-arid climates" from "cold semi-arid climates," there are three widely used isotherms: Either a mean annual temperature of 18°C, or a mean temperature of 0°C or −3°C in the coldest month, so that a location with a "BS" type climate with the appropriate temperature above whichever isotherm is being used is classified as "hot semi-arid" (BSh), and a location with the appropriate temperature below the given isotherm is classified as "cold semi-arid" (BSk).

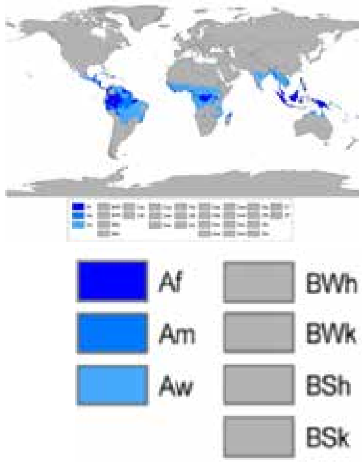
Hot semi-arid climates (type "BSh") tend to be located in the 20s and 30s latitudes (tropics and subtropics), typically in close proximity to regions with a tropical savannah climate or a humid subtropical climate. These climates tend to have hot, sometimes extremely



[Fig-6] Semi-Arid Areas

hot, summers and warm to cool winters, with some to minimal precipitation. Hot semi-arid climates are most commonly found around the fringes of subtropical deserts, most commonly found in Africa, Australia and South Asia. In Australia, a large portion of the Outback surrounding the central desert regions lies within the hot semi-arid climate region. In South Asia, both India and sections of Pakistan experience the seasonal effects of monsoons and feature short but well-defined wet seasons but is not sufficiently wet overall to qualify as a tropical savannah climate. Hot semi-arid climates can also be found in Europe (primarily in Spain), [33] parts of North America, such as in Mexico, areas of the Southwestern United States, and sections of South America such as the sertão, the Gran Chaco, and on the poleward side of the arid deserts where they typically feature a Mediterranean precipitation pattern, with generally rainless summers and more wet winters.

1.8 Tropical



[Fig-7] Tropical Climate

The tropics [Fig-7] are a region of the Earth surrounding the Equator. They are delimited in latitude by the Tropic of Cancer in the Northern Hemisphere at 23°26′12.8″ (or 23.43688°) N and the Tropic of Capricorn in the Southern Hemisphere at 23°26′12.8″ (or 23.43688°) S. Tropical is sometimes used in a general sense for a tropical climate to mean warm to hot and moist year-round, often with the sense of lush vegetation.

Many tropical areas have a dry and wet season. The wet season, rainy season or green season is the time of year, ranging from one or more months, when most of the average annual rainfall in a region falls. [34]

Areas with wet seasons are disseminated across portions of the tropics and subtropics. [35] Under the Köppen climate classification, for tropical climates, a wet-season month is defined as a month where average precipitation is 60 mm (2.4 in) or more. [36] Tropical rainforests technically do not have dry or wet seasons, since their rainfall is equally distributed through the year. [37] Some areas with pronounced rainy seasons see a break in rainfall during mid-season when the intertropical convergence zone or monsoon trough moves poleward of their location during the middle of the warm season. [38] Typical vegetation in these areas ranges from moist seasonal tropical forests to savannahs.

When the wet season occurs during the warm season, or summer, precipitation falls mainly during the late afternoon and early evening hours. The wet season is a time when air quality improves, freshwater quality improves and vegetation grows significantly, leading to crop yields late in the season. Floods cause rivers to overflow their banks, and some animals to retreat to higher ground. Soil nutrients diminish and erosion increases. The incidence of malaria increases in areas where the rainy season coincides with high temperatures. Animals have adaptation and survival strategies for the wetter regime. Unfortunately, the previous dry season leads to food shortages into the wet season, as crops have yet to mature.

However, regions within the tropics may well not have a tropical

[Fig-8] A Dusting of Snow in the Atacama Desert

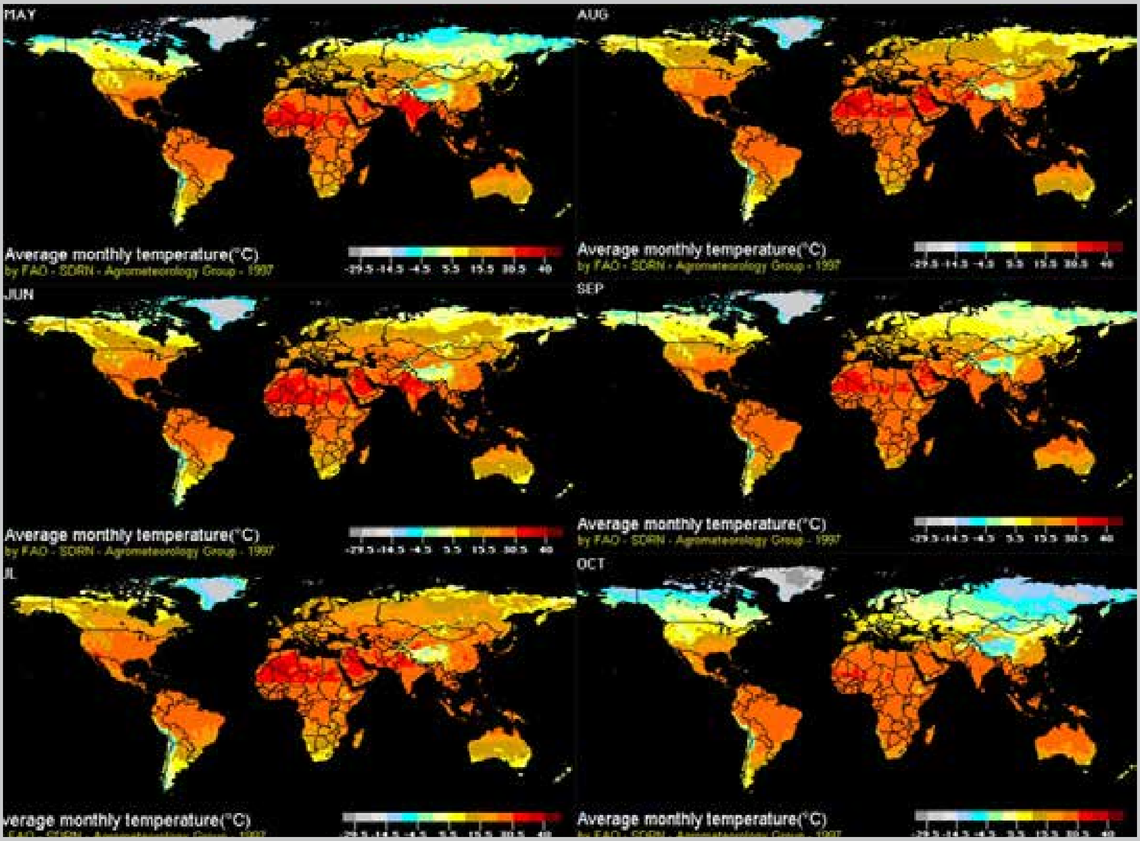
climate. Under the Köppen climate classification, much of the area within the geographical tropics is classed not as "tropical" but as "dry" (arid or semi-arid), including the Sahara Desert, the Atacama [Fig-8] Desert and Australian Outback. Also, there are alpine tundra and snow-capped peaks, including Mauna Kea, Mount Kilimanjaro, and the Andes as far south as the northernmost parts of Chile and Argentina.

1.9 Hot Climates of the World

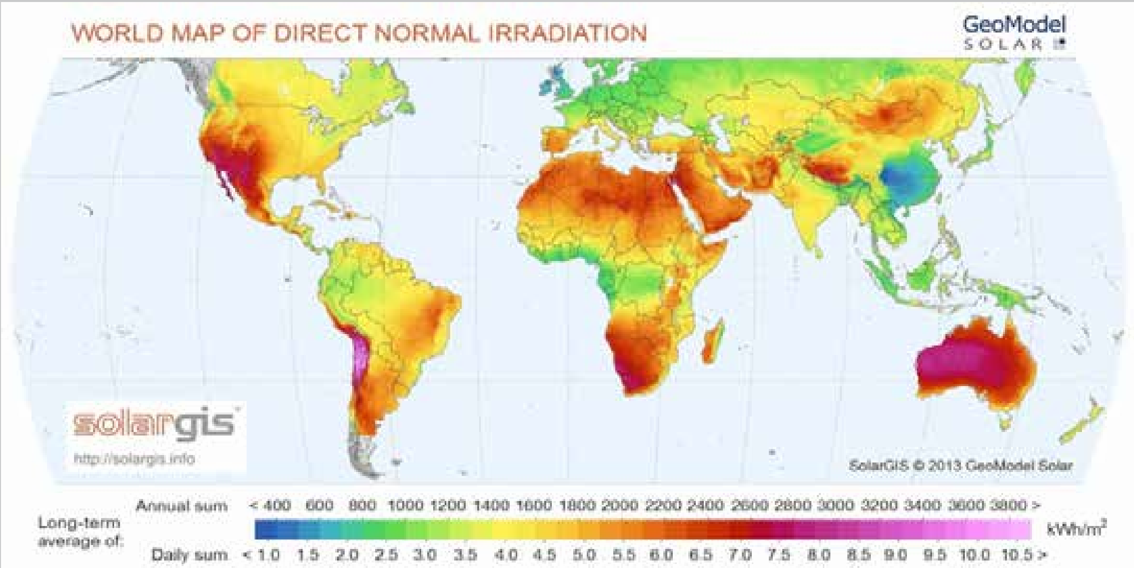
This research is designed to provide more answers and help people who live in hot temperatures live more comfortably. Therefore, these solutions need to have a clear vision about where hot or extremely hot conditions exist in the world. [Fig-9] [39]
Here we can see the temperatures of the world from May to October in 1997. We are interested in the locations that have more than 27° C average during these months.

1.9.1 Global Sun Radiation

Sun radiation is the main reason for the warming of the Earth. The areas that have a lower distance and lower angles with the sun receive more radiation and continue to have higher temperatures. [Fig-10] This map of Irradiation demonstrates this.

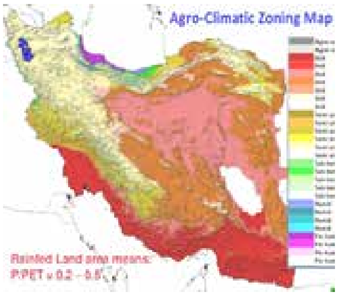


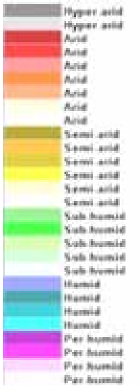
[Fig-9] World Temperatures from May to October



[Fig-10] Map of Irradiation

1.10 Climate and Typology of Vernacular Architecture of Iran





[Fig-11] Iran Climate Map

There is a misconstrued perception by Western people about the climate in Iran. [Fig-11] Usually, people think that all parts of Iran are hot and have desert conditions, and people in the desert move around with camels. The reality is that there are also cold temperatures and snow or moderate Mediterranean climates in Iran. We can generally classify climates in Iran in four different categories, based on different characteristics of heat, humidity and height. Therefore, through the years, Persians arranged their architecture and construction methods in different ways based on climate characteristics, their lifestyles and the use of different materials.

1.10.1. Northern Iran – Moderate and Humid Weather [Fig-12]

The entire southern coastline of the Caspian Sea stretches from the northwest to the northeast of the country, and is positioned just north of the Alborz Mountains. The particular position of the south Caspian Sea coastline north of the Alborz Mountains stretches from northwest to northeast, which consists of the entire southern coast of the Caspian Sea. Thus, the Alborz Mountains creates a high and long wall between the Caspian Sea and the central parts of Iran. Its natural wall traps the humidity in the northern part, and as a result, there is a moderate and humid and rainy green coastline, similar to a Mediterranean climate in the northern part of Iran. In the southern part, there is a dry and desert climate.
Traditional architecture in northern Iran is based on the existing materials in this area, which are made of mostly wood from forests. They built inclined roofs due to the high rate of rainfall and in order to avoid capillary effects, the buildings usually do not have underground floors. The ground floor is typically one meter above the natural soil level. Other characteristics include the use of balconies and large windows.

[Fig-12] Traditional Architecture of Northern Iran with Mediterranean Climates

[Fig-13] Top: View of the City of Bushehr, Southern City in Iran - Down: House in Bandar Lengeh

1.10.2 Southern Iran – Low Rain in Dry and High Humidity Weather [Fig-13]

Southern Iran is located in the north tropical latitude, so this area is warmer than other parts in the winter. It is rarely lower than 10° C and because of its vicinity with the Persian Gulf, it is very humid.
Traditional architecture in this area is based on wind circulation from the coastline and ocean with very simple and massive wind capture towers and high walls with big windows. The palm tree is the typical tree of this area. Traditional buildings have (Ashoodan) which are underground floors, and the place where people pass their time during summer afternoons.

[Fig-14] Top: View of Zagros Mountain in West of Iran. Down: Palangan village

1.10.3 Western Iran – Cold and Dry Weather

The Zagros Mountains [Fig-14] is the longest mountain range in the country, stretching from the northwest to southwest of the country. Typically, this area's whether in summer is moderate and winter is cold and snowy.
Traditional architecture of this area generally is created by stones, wood and beaten raw clay (adobe). The buildings tend to have semi-ground floors and window openings are usually facing the south in order to capture more natural sunlight in winter.

1.10.4 Central and Eastern Iran (Desert Area)

It is always dry and extremely hot during the six months of summer, with considerate differences between night and day temperatures.
The central part of Iran contains many different deserts, such as Kavir-e-Lut, [Fig-15] and Dashte-e-Kavir. It has very hot temperatures and the lake water and rainfall make it one of the more difficult parts of the country in which to live. However, hardworking and creative people found complex solutions to convert it into a more habitable environment and created very beautiful cities like Yazd, [Fig-16] Kasha, Fahraj and others.
Buildings are concentrated close together, using thick walls made of argils-Caley-adobe, Bâd-gir (wind-towers), and evaporation had created improved situations for cooler air. Pure water is conserved and used in the hot summers through digging (Qanat) [Fig-17] long underground tunnels, which bring water from 20 to100 km away in water resources to cities, making cisterns.

ertdfv

[Fig-15] Lut Desert in Central Iran (Kavir-e-Lut)

[Fig-16] View of Yazd, from the Main Cistern to the Central Mosque

[Fig-17] Qanat, Iranian Water Underground System

1.11 Global Warming Problem

“18 January 2018 (WMO) - In a clear sign of continuing long-term climate change caused by increasing atmospheric concentrations of greenhouse gases, 2015, 2016 and 2017 have been confirmed as the three warmest years on record. 2016 still holds the global record, whilst 2017 was the warmest year without an El Niño, which can boost global annual temperatures. [Fig-18]

A consolidated analysis by the World Meteorological Organization of five leading international datasets showed that the global average surface temperature in 2017 was approximately 1.1° Celsius above the pre-industrial era.

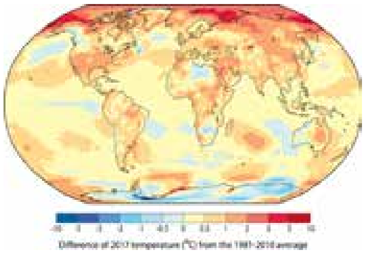
The year 2016 remains the warmest year on record (1.2°C above preindustrial era). Global average temperatures in 2017 and 2015 were both 1.1°C above pre-industrial levels. The two years are virtually indistinguishable because the difference is less than one hundredth of a degree, which is less than the statistical margin of error.

“The long-term temperature trend is far more important than the ranking of individual years, and that trend is an upward one, “said WMO Secretary-General Petteri Taalas. “Seventeen of the 18 warmest years on record have all been during this century, and the degree of warming during the past three years has been exceptional. Arctic warmth has been especially pronounced and this will have profound and long-lasting repercussions on sea levels, and on weather patterns in other parts of the world.”

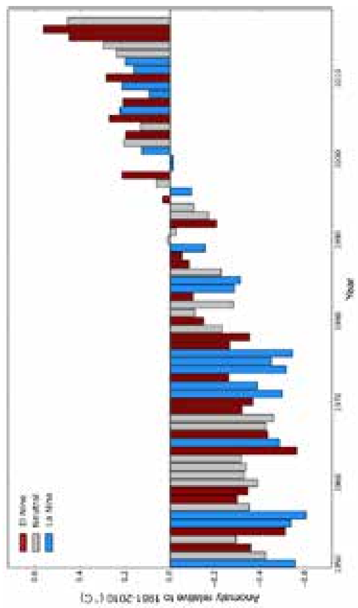
The globally averaged temperature in 2017 was about 0.46°C above the 1981-2010 long-term average (14.3°C). This 30-year baseline is used by national meteorological and hydrological services to assess the averages and variability of key climate parameters, such as temperature, precipitation and wind, which are important for climate sensitive sectors such as water management, energy, agriculture and health. [Fig-19]

n addition to the global warming due to rising greenhouse gas levels in the atmosphere, the climate also has a naturally occurring variability due to phenomena such as El Niño, which has a warming influence, and La Niña, which has a cooling influence. The strong

2015/2016 El Niño contributed to the record temperature in 2016. By contrast, 2017 started with a very weak La Niña and also finished with a weak La Niña.
“Temperatures tell only a small part of the story. The warmth in 2017 was accompanied by extreme weather in many countries around the world. The United States of America had its most expensive year ever in terms of weather and climate disasters, whilst other countries saw their development slowed or reversed by tropical cyclones, floods and drought,” said Mr Taalas.” [40]



[Fig-18] difference of the temperature from 2081-to 2017



[Fig-19] Anomaly relative 1981-2017

1.12 Energy and Ecologic Disaster

[Fig-20] Fukushima Nuclear Power Plant Explosion

[Fig-21] Drying Orumieh Lake in Northwestern Iran

Recently, several ecological disasters have occurred on our planet. These include the transport and spill of oil into the oceans; nuclear disasters in nuclear electric-centers [Fig-20]; the drying of lakes [Fig-21] due to dams which caused many fish and other animals to die; air pollution; micro-dust at the bottoms of lakes; and climate change.

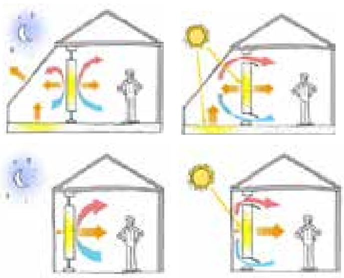
The Chernobyl disaster was the worst nuclear catastrophe in history. Today, the deserted station is surrounded by a Zone of Exclusion 30 km in radius. The fourth reactor was working for only three years, when it suddenly exploded on April 26, 1986. The explosion threw eight tons of radioactive fuel into the atmosphere. 237 people suffered from acute radiation sickness immediately following the accident. 31 of them died within the following three months. Reported thus far are 237 cases of acute radiation sickness and 31 deaths. [41]

Cancer deaths caused by Chernobyl may reach a total of about 4,000 among the five million people residing in the contaminated areas. [42] Following the disaster itself, the Soviet Union had organized efforts to stabilize and shore up the reactor area, still awash in radiation, using the efforts of more than 600,000 liquidators (civil and military personnel) recruited from all over the USSR. They are widely credited with limiting both the immediate and long-term damage from the disaster. Some organizations claim that deaths as a result of the immediate aftermath and the cleanup operation may number at least 6,000. [43]

1.12.1 Common Cooling Systems

The energy expended on the heating, cooling, and control of humidity in buildings is considerable. If this energy, now produced from fossil fuels, could be saved and climate control could be achieved by some other means for example, the United States alone would save over 25 % of its energy needs. About 29 % of global warming emissions come from our electricity sector. In contrast, most renewable energy sources produce little to no global warming emissions. [44]
In recent decades, an expensive and uncomfortable architecture has been introduced to the hot and arid regions of the Middle East. This type architecture is mainly based on the concepts of the Modern Movement. This architecture, which is sometimes known as international architecture, does not respect the climate of the region and relies on mechanical equipment. “The temptation to create up-to-date designs, which assails a modern architect, prevents him from achieving the chief aim of architecture: to be functional. He forgets the environment into which he will implant his buildings because he is attracted by new and modem innovations and gadgetry. He fails to realize that form has meaning only within the context of its environment. The architect who builds solar furnace and then introduces a vast refrigerating plant to make it habitable is underestimating the complexity of the problem and working below the proper standards of architecture.” [45]
While in the hot dry regions, the energy used for heating is not significant. The major problem is the great demand for air conditioning and refrigeration. Ultimately, passive devices will be a natural solution for the next generations. However, climate change and using renewable sources of energy will alter all these problems.

[Fig-22] Normal Warming Systems



[Fig-23] New Passive Technological Natural Source Warming Systems

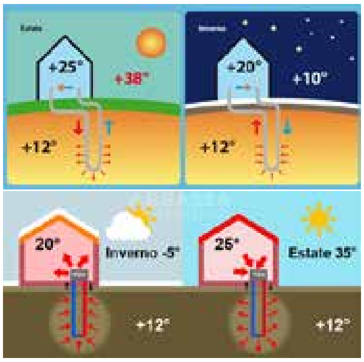
1.12.2 Cold Seasons

During cold seasons, we typically use different types of energy in many buildings. These include gas, oil, fossil fuel or electricity. [Fig-22] Through the development of material science and environmental architecture as a new branch of architecture, architecture science, as a proper tool for sustainable approaches, will help in the construction of buildings. In regards to new passive technology methods, we can use tools such as: geothermal circulation, solar panels, photovoltaic panels, Trombe-walls or sun-spaces etc.[Fig-23]

1.12.3 Hot Seasons

On the contrary, during hot seasons, we usually just use electricity for ventilators, chillers or other kinds of cooling systems.
[Fig-24]However, more than a thousand years ago, Middle Easterners found different ways to use natural techniques in creating a livable environment inside their buildings, without the use of any electric power. They used wind-towers and evaporation systems. It is worth noting that in last year's architecture practices, architects and engineers found new ways to use passive ventilation too. This included the use of chimney effects, geothermal systems, photovoltaic panels etc. [Fig-25]

[Fig-24] Common Cooling Systems



[Fig-25] Geothermal – Passive Cooling and Warming Systems

1.13 Conclusion

The conclusion of this chapter will answer the following questions:

- **What are the climate objectives of this research?**
  The primary climates are
  A.BWh = hot desert climate,
  B.BWn = desert climate with frequent fog and BSh = hot semi-arid and climate BSk
  These landscapes could be useful for all of the areas that have high temperatures and long summers like: Cwa, Cfa ,Csa ,Af, Am or As.

- **What is the main climate in the Middle East?**
  BWh = Hot desert climate

- **What is more useful for architecture to know – Climate or Micro-Climate?**
  The answer is both. For general information, architects need to know about the climate of the area, like temperature, main wind direction, relative humidity, rainfall, maximum temperatures in summer, lower temperatures in winter, and the precise behavior of natural elements like wind. We must study micro-climate in order to understand the other natural or urban factors that will affect the behavior of climate in the area.

- **Is it necessary to study architecture based on climate?**
  Absolutely yes. History shows us that every place on Earth has different types of architecture, and in order to create architecture with a sustainable identity, it must evidently know the climate context.

1.14 End Notes

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CHAPTER 2

Effects of Hot climate on Poverty and Food Security in developing Countries and the Role of International Organizations and Sustainable Architectural Solutions

2.1 Objective

- Compare the hot climate and low income countries on the world map
- Present a map and list of the world's most low-income countries
- Look at the populations of the world's most impoverished countries versus richest countries
- Provide a clear outlook on the issue of poverty and food security in developing countries, and the biggest problems facing them today
- Present the most renowned humanitarian agencies that improve food security and education
- Analyze how conservation can help the food security problem
- Examine how sustainable architecture can provide concrete solutions to these problems
- Discover how passive architecture can lower greenhouse emissions and have a positive effect on climate change

2.2 Poverty

Causes of poverty are changing trends in a country's economy. Associated with the lack of education, high divorce rate, a culture of poverty, overpopulation, epidemic diseases such as AIDS and malaria and environmental problems such as lack of rainfall.
Almost 50 percent of people in the world today live on less than $2.50 per day.

2.2.1 Defining of a Developing Country

The term developing country can be used to describe a variety of countries that can also be labeled as a low or middle-income country (LMIC), less economically developed country (LEDC), underdeveloped country, newly industrialized country, emerging market, and least developed country. In this chapter, we will refer low-income and lower middle-income countries as developing countries.
There are many ways to categorize a developing country. The major factors include the level of industries, the Human Development Index (HDI), and their Gross National Income (GNI) per capita, relative to other countries. "The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI can also be used to question national policy choices, asking how two countries with the same level of GNI per capita can end up with different human development outcomes. The health dimension is assessed by life expectancy at birth, and the education dimension is measured by mean of years of schooling for adults aged 25 years and more, and expected years of schooling for children of school entering age. The standard of living dimension is measured by gross national income per capita." [1]

2.2.2 World's Most Impoverished Countries

For the 2017 fiscal year, "low-income economies are defined as those with a GNI per capita, calculated using the World Bank Atlas method, of $1,025 or less in 2015; lower-middle-income economies are those with a GNI per capita between $1,026 and $4,035; upper-middle-income economies are those with a GNI per capita between $4,036 and $12,475; high-income economies are those with a GNI per capita of $12,476 or more." [2]
Below is the official list of least developed countries in the world (LDCs). The year in brackets indicates the year the UN included them in this category. [Tab-1]
Below is a map indicating which income bracket each country falls under. Dark blue indicates the lowest income countries, while dark red indicates the highest income countries. It is clear that the majority of low-income countries are located in warm climate areas. With the exceptions of Israel and the oil rich Gulf nations, the countries that are furthest to the north and south of the Equator are the wealthiest, while the overwhelming majority of the most impoverished countries are located in close proximity to the Equator. The majority are located in Sub-Saharan Africa. With the exception of Western Europe, landlocked countries also tend to be poorer than their neighboring countries that have access to a body of water.
[Fig-1]
The poverty headcount ratio — also referred to as the extreme poverty rate — is the share of the population living on less than $1.90 a day in 2011 purchasing power parity terms. The $1.90 a day poverty line reflects the value of national poverty lines of some of the poorest countries in the world. Consumption and income data used for estimating poverty are collected from household surveys. This map shows the country-level poverty estimates used to generate the 2013 regional and global poverty estimates, which draw on data from more than 2 million randomly sampled households, representing 87% of the total population in 138 low- and middle-income countries, high-income countries eligible to receive loans from the World Bank (such as Chile), and recently graduated countries (such as Estonia). [5] [Fig-2]

United Nations
Committee for Development Policy
Development Policy and Analysis Division
Department of Economic and Social Affairs

List of Least Developed Countries (as of March 2018)*, **

Afghanistan (1971)	Malawi (1971)
Angola[1] (1994)	Mali (1971)
Bangladesh (1975)	Mauritania (1986)
Benin (1971)	Mozambique (1988)
Bhutan (1971)	Myanmar (1987)
Burkina Faso (1971)	Nepal (1971)
Burundi (1971)	Niger (1971)
Cambodia (1991)	Rwanda (1971)
Central African Republic (1975)	Sao Tome and Principe (1982)
Chad (1971)	Senegal (2000)
Comoros (1977)	Sierra Leone (1982)
Democratic Republic of the Congo (1991)	Solomon Islands (1991)
Djibouti (1982)	Somalia (1971)
Eritrea (1994)	South Sudan (2012)
Ethiopia (1971)	Sudan (1971)
Gambia (1975)	Timor-Leste (2003)
Guinea (1971)	Togo (1982)
Guinea-Bissau (1981)	Tuvalu (1986)
Haiti (1971)	Uganda (1971)
Kiribati (1986)	United Republic of Tanzania (1971)
Lao People's Democratic Republic (1971)	Vanuatu[2] (1985)
Lesotho (1971)	Yemen (1971)
Liberia (1990)	Zambia (1991)
Madagascar (1991)	

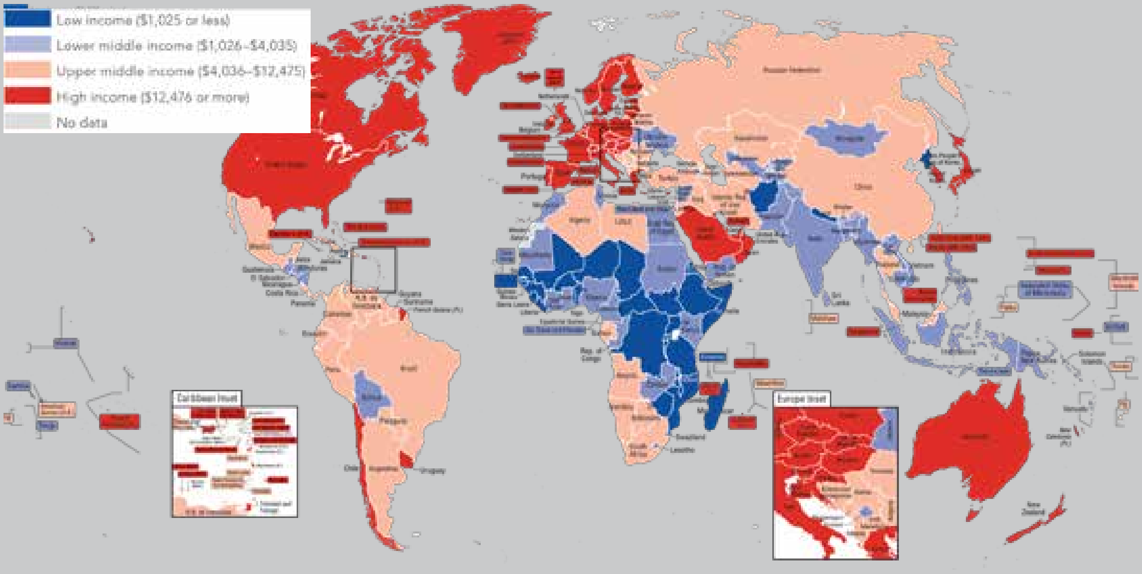
* *The list will be updated when new decisions become available.*

** *Year of inclusion on the list in brackets.*

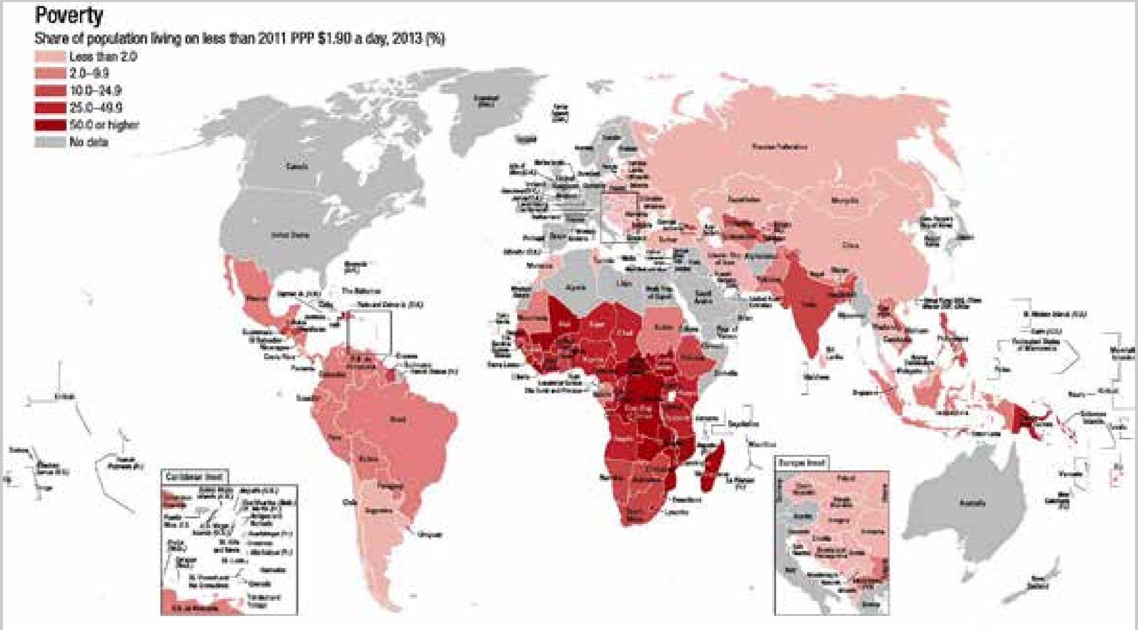
[1] General Assembly resolution A/RES/70/253 adopted on 12 February 2016, decided that Angola will graduate five years after the adoption of the resolution, i.e. on 12 February 2021.

[2] General Assembly resolution A/RES/68/18 adopted on 4 December 2013, decided that Vanuatu will graduate four years after the adoption of the resolution on 4 December 2017. General Assembly resolution A/RES/70/78 adopted on 9 December 2015, decided to extend the preparatory period before graduation for Vanuatu by three years, until 4 December 2020, due to the unique disruption caused to the economic and social progress of Vanuatu by Cyclone Pam.

[Tab-1] [3]



[Fig-1] The World by Income FY2017 [4]



[Fig-2] Poverty – Share of Population Living on Less Than 2011 $1.90 a Day [6]

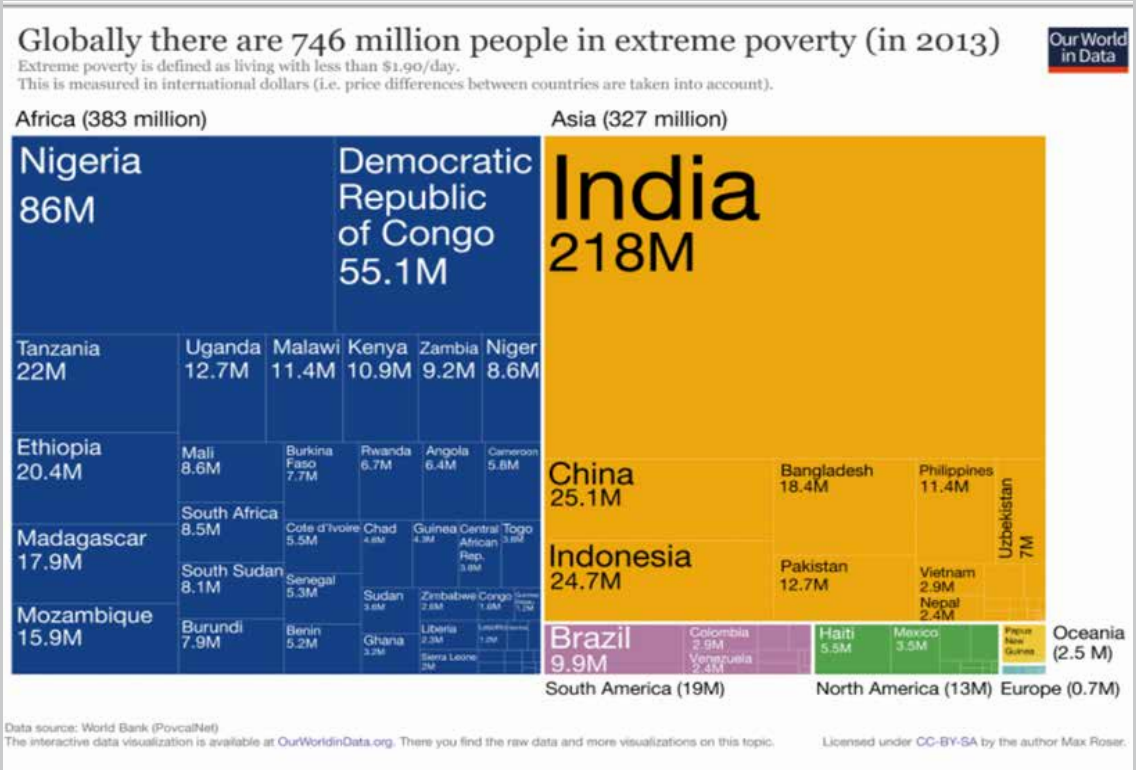
2.2.3 Developing Country Populations and Hot Climate Areas

While the percentage of people living in extreme poverty (earning less than $1.90 a day) has decreased dramatically over the last two hundred years, in 2015, we still have about 705 million people that fall into this category. The good news is that this number has significantly decreased from the two billion that existed in 1990, less than 30 years ago. This means that on average, every day in the 25 years between 1990 and 2015, 137,000 fewer people were living in extreme poverty. [7]
According to the most recent estimates, in 2015, 10 % of the world's population lived on less than $1.90 USD a day, compared to 11% in 2013. That's down from nearly 36% in 1990.
However, there is no reason to be complacent. "While poverty rates have declined in all regions, progress has been uneven. Two regions, East Asia and Pacific (47 million extreme poor) and Europe and Central Asia (7 million) have reduced extreme poverty to below 3 %, achieving the 2030 target.
Another issue that arises in warm climates, particularly in tropical climates, is the low crop yield facing farmers. Climate change is affecting the timing and length of the growing seasons, as well as soil temperature and moisture conditions. [8] "The food security threat posed by climate change is greatest for Africa, where agricultural yields and per capita food production has been steadily declining, and where population growth will double the demand for food, water, and livestock forage in the next 30 years." [9]

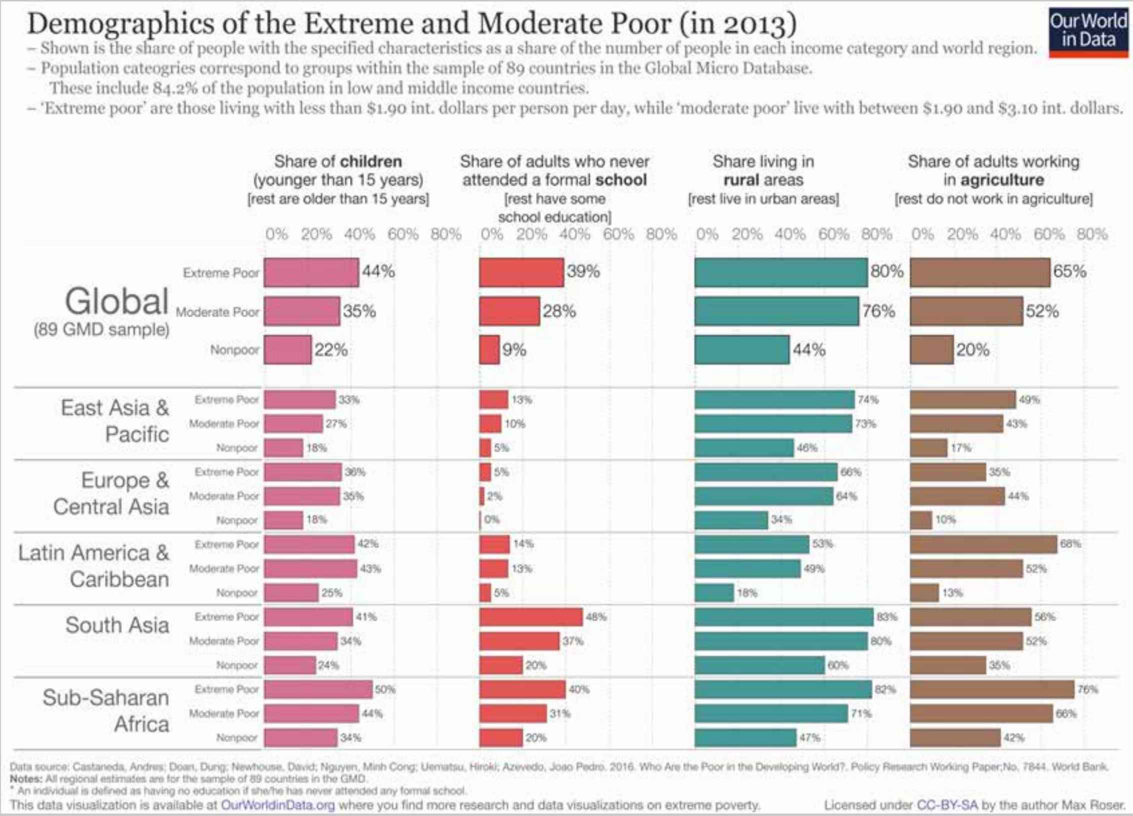
2.2.4 Demographics of Most Affected by Poverty

More than half of the extreme poor live in Sub-Saharan Africa. In fact, the number of poor in the region increased by 9 million, with 413 million people living on less than $1.90 USD a day in 2015, more than all the other regions combined. If the trend continues, by 2030, nearly 9 out of 10 extreme poor will be in Sub-Saharan Africa. The majority of the global poor live in rural areas, are poorly educated, employed in the agricultural sector, and under 18 years of age." [10] As usual with World Bank estimates, poverty measures are adjusted to account for differences in price levels between countries. This is reflected in the 'international dollar' metric used to measure

incomes.
As we can see, today, Africa is the continent with the largest number of people living in extreme poverty. The breakdown by continent is as follows:
383 Million in Africa
327 Million in Asia
19 Million in South America
13 Million in North America
2.5 Million in Oceania
0.7 Million in Europe
Below, we can also see that India is the country with the largest number of people living in extreme poverty (218 million people), with Nigeria and the Congo (DRC) following with 86 and 55 million people, respectively.
These figures are the result of important changes across time. As we mentioned above in our discussion of regional trends, in 1990, Asia was the world region with the largest number of poor people (505 million in South Asia, plus 966 million in East Asia and the Pacific). However, with rapid economic growth in Asia over the past two decades, poverty in Asia fell more rapidly than in Africa. [11] [Tab-2]
The following visualization uses this source to provide a characterization of those who live in extreme poverty. As we can see, across all world regions, the poor tend to be young and live in rural areas. [Tab-3]
The demographics in this chart above demonstrate that poverty levels are especially high among children (aged 15 and under) in extreme and moderately poor countries. On a global level, 44% of children live with less than $1.90 USD a day, 50% are in Sub-Saharan Africa. 80% of the extreme poor live in rural areas, with 65% working in the agricultural sector.
Another important point to pull from these figures is the percentage of adults who never received any form of formal education. The global numbers is 39% for the extreme poor, while only 9% for the non-poor. Clearly, education is a key component in helping people escape poverty. There will be more discussion on education in a later section. [Tab-4]

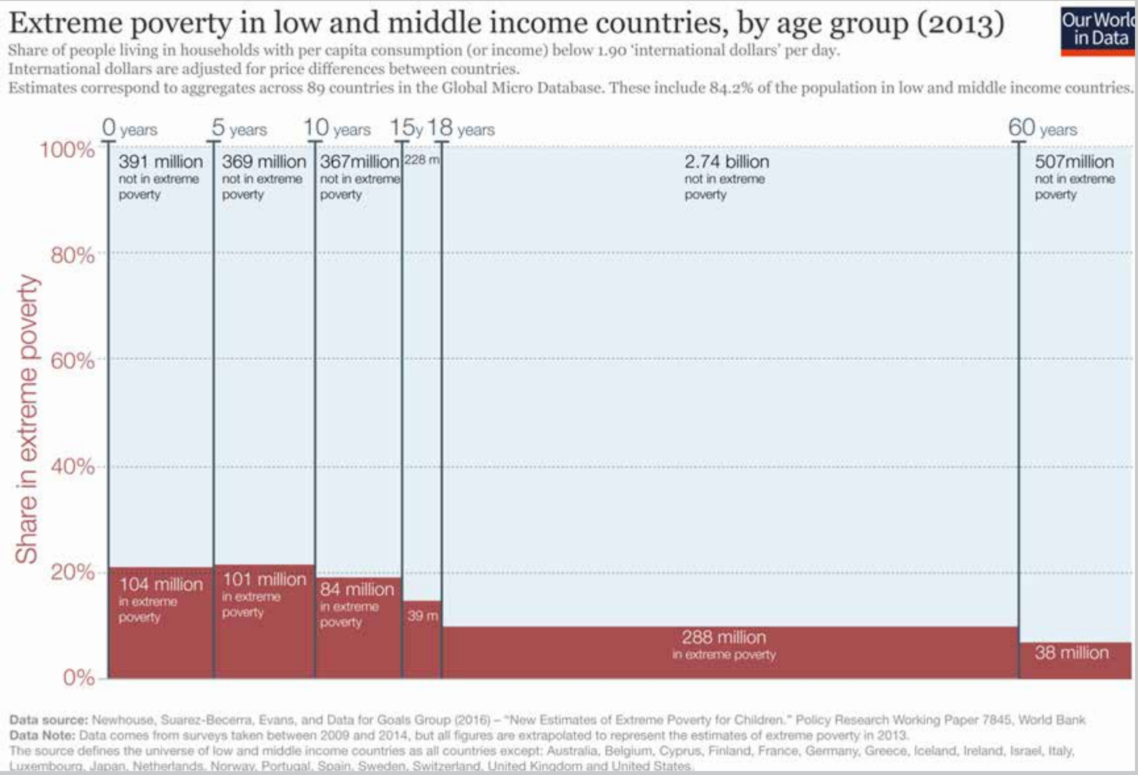


[Tab-2] Poverty – Share of Population Living on Less Than 2011 $1.90 a Day [6]

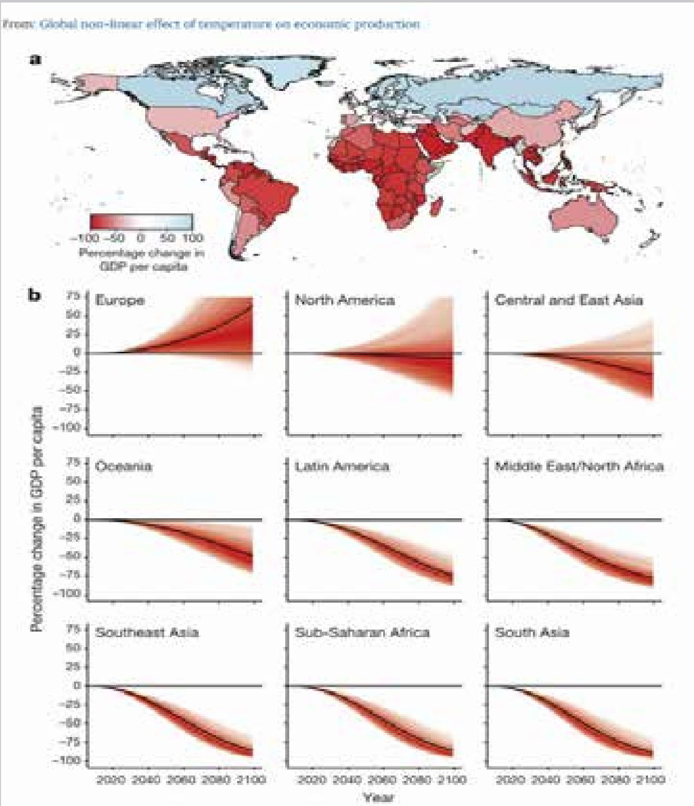


[Tab-3] Demographics of the Extreme and Moderate Poor 2013 [13]

2. 3. 4.



[Tab-4] Extreme Poverty in Low and Middle-Income Countries by Age Group [14]



[Fig-3] Projected Effect of Temperature Changes on Regional Economies [19]

2.2.5 Distinguishing Factors of World's Lowest and Highest Income Countries

Several major factors come into play to determine whether a country is rich or poor. Institutions are the biggest contributor to a country's level of development and wealth. There is a direct correlation between poverty and levels of corruption. The least corrupt countries are the richest, while the most corrupt are the poorest.
When they are corrupt, the government cannot collect enough taxes to get the funds they need to build the proper institutions to create wealth and escape poverty. These institutions include education, health, police, and infrastructure. Half the wealth of the world's 20 poorest countries goes to off shore accounts. Corruption also relates to nepotism and lack of meritocracy, which pushes out the possibility for the most deserving, best fitting people to fill top-level positions, which in turn, keeps innovation and efficiency down.
Culture is a set of customs, behavior and beliefs of a specific group of people. In general, the least religious people are, the wealthier they tend to be. In 19 of the 20 richest countries in the world, with the exception of the United States, 70% of their population do not count religion as an important aspect of their life. In the poorest countries, the overwhelming majority of the population are strongly religious. In the richest countries, a majority of people believe in their capacity to alter their destiny through effort and talent. The one exception is the U.S., where Christian Protestant beliefs of hard work and discipline is closely tied to capitalism and attaining wealth. [15]
Geography or latitude is another major factor to a country's level of wealth. Low-income countries are overwhelmingly located in tropical (and some very arid) regions. Agriculture is a major component of development that contributes to poverty. Tropical plants are a lot less full of carbohydrates. Also, the general quality of the soil is worse than in cooler countries. Tropical climate can also be disadvantageous to photosynthesis. Historically, a key determinant of the likelihood a society could grow in wealth was its possession of large domesticated animals, such as horses and oxen. They freed up a large part of the workforce, which involved plowing land by hand. In tropical Africa however, domesticated animals throughout its history, have been devastated by certain flies (in particular, the tse tse fly), present due to heat and humidity. They caused domesticated animals throughout the continent to be inactive. This has thus had a profound effect on African society, and has slowed the development

of technology, decreased agricultural productivity and stumped the creation of wealth. In addition, the geography of these low-income countries causes humans to be susceptible to a variety of diseases, such as arboviruses like dengue, yellow fever, and ebola; bacterial infections such as cholera, tuberculosis and e-coli; and parasitic diseases such as malaria and cysticercosis. Low-income countries are often affected by a variety of these diseases simultaneously.

Another major issue related to geography is climate and how it relates to a population's productivity. Growing evidence demonstrates that climatic conditions can have a profound impact on the functioning of modern human societies, but effects on economic activity appear inconsistent. Fundamental productive elements of modern economies, such as workers and agricultural products, exhibit highly non-linear responses to local temperature, even in wealthy countries. [16] In contrast, aggregate macroeconomic productivity of entire wealthy countries is reported not to respond to temperature, while poor countries respond only linearly. [17] We show that overall economic productivity is non-linear in temperature for all countries, with productivity peaking at an annual average temperature of 13 °C and declining strongly at higher temperatures. The relationship is globally generalizable, unchanged since 1960, and apparent for agricultural and non-agricultural activity in both rich and poor countries. These results provide the first evidence that economic activity in all regions is coupled with the global climate and establishes a new empirical foundation for modelling economic loss in response to climate change with important implications. If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change. [18] [Fig-3]

We find country-level economic production is smooth, non-linear, and concave in temperature, when there is a maximum at 13 °C, well below the threshold values recovered in micro-level analyses. Cold-country productivity increases as annual temperature increases, until the optimum. Productivity declines gradually with further warming, and this decline accelerates at higher temperatures. [20]

- Lack of connectivity is another factor that contributes to the level of low or high income of a country. In general, low-income countries tend to be very badly connected. Landlocked countries are particularly vulnerable. Bolivia, one of the two only landlocked countries in South America is also the poorest in the continent. Africa has 15 landlocked countries, with just one major navigable river, the Nile. 11 of these 15 have average yearly income of $1,025 USD or less. Asia's poorest nation, Afghanistan, is also landlocked.

- Natural resources like oil and precious metals, is another factor that greatly influences a country's development. Ironically, many low-income countries have plenty of resources. Economists call these resources "intensifiers," meaning that they tend to make rich countries richer and poor countries poorer. For example, the Democratic Republic of Congo is one of the world's most mineral rich countries. These plentiful resources cause the country's elites to grab money, rather than efficiently use them to build wealth-creating industries. The wealth from coltan minerals for example, funds DRC rebels and their horrific actions throughout the country. [21]

2.3 Food Security

One of out of six people on our planet go to sleep hungry every night. 25,000 people die from hunger and malnutrition related diseases every single day. [22] Recent studies suggest that the world will need roughly 70% to 100% more food by 2050. [23] This current year (2018), for the third year in a row, there has been a rise in world hunger. The absolute number of undernourished people, i.e. those facing chronic food deprivation, has increased to nearly 821 million in 2017, from around 804 million in 2016. These are levels from almost a decade ago. [24] [Fig-4]

[Fig-4] A Severely Malnourished Girl is Weighed at the Aslam Health Center in Hajjah, Yemen. Photo by Hammadi Issa, AP

2.3.1 Defining Food Security

Food security has been defined as the availability of food and people's access and affordability to it. The Food and Agriculture Organization (FAO) of the United Nations specifically defines it as existing "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life." [25]
Sub-Saharan Africa has the highest proportion of undernourished with 30% of the population being in this category. Food security is affected by climate change, dependence on fossil fuels, and the loss of biodiversity and use of food crops for biofuels, among many other factors. [26]
According to the U.S. Department of Agriculture, food insecurity is a situation of "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways." [27] Examples of food insecurity include famines, most commonly caused by draughts or wars, but often the most significant famines in history have been caused by economic policies. Food shortages in a population are caused either by a lack of food or by difficulties in food distribution; it may be worsened by natural climate fluctuations and by extreme political conditions related to oppressive government or warfare. [28]

Although there are strong commitments by governments and international organizations around the world to combat hunger, food insecurity still represents one of the biggest challenges facing a very large part of the global population.

There are our four generally recognized dimensions of food security. They are availability, access, and utilization (use and misuse), and stability. [29]

- **Food availability** is basically the production and supply of food though production, distribution and exchange. [30] It often remains the predominant aspect used in food security analysis and measurement. Indicators used to measure food availability include crop production and/or food production indices, livestock ownership indices, and national food balance sheets. [31] Food distribution involves the storage, processing, transport, packaging, and marketing of food. [32] Food-chain infrastructure and storage technologies on farms can also affect the amount of food wasted in the distribution process. Poor transport infrastructure can increase the price of supplying water and fertilizer as well as the price of moving food to national and global markets. [33] Around the world, few individuals or households are continuously self-reliant for food. The exchange of food requires efficient trading systems and market institutions, which can affect food security. Per capita world food supplies are more than adequate to provide food security to all, and thus food accessibility is a greater barrier to achieving food security. [34]

- **Access,** or the ability to acquire a sufficient quantity and quality of food, is influenced by income level, access to resources, physical and social environment, the cost of food, and government and trade policies. Access also refers to the preferences to individuals and households. There are two general types of access: direct, where a household produces food using its own human and material resources: and economic access, where a household purchases food produced somewhere else. [35] Access to food is often measured using proxy, entitlements-based indicators such as food consumption, food price monitoring, income, or assets. For example, in rural Sub-Saharan Africa, the majority of the population practices subsistence agriculture, and supplements food stores with purchases from the market. There is often a ‘‘hungry season,’’ which occurs when food stores are inadequate to carry a household to the next harvest, and people are particularly dependent upon market purchases. [36]

- **Food utilization** is the actual consumption of food by individuals, and it is determined by the ability to physically use the available food (e.g., having proper cooking utensils, culturally regulated feeding hierarchies, cuisine patterns, adequate housing) and the ability to biologically use the available food (e.g., absence of diarrheal or other diseases that impede biological food use, infection, etc.) [37] Food safety affects food utilization, since it can be affected by the preparation, processing and cooking of food in the community and household. [38] Sanitation, access to healthcare and education about nutrition and food preparation can all affect food utilization. [39]

- **Stability** refers to the ability to obtain food over a period of time. Food insecurity can be transitory, seasonal or choric, which is the long-term lack of sufficient food. [40] Several factors can affect stability, such as natural disasters, droughts, instability in markets, and loss of employment or productivity. [41]

2.3.2 Challenges and Risks to Food Security

- **Global Water Crisis**
  The lack of water of course, has an adverse effect on food security around the world. Water deficits, which are already spurring heavy grain imports in numerous smalle,r countries may soon do the same in larger countries. [42] Regionally, Sub-Saharan Africa has the largest number of water-stressed countries of any place on the globe, as of an estimated 800 million people who live in Africa, 300 million live in a water-stressed environment. It is estimated that by 2030, 75 million to 250 million people in Africa will be living in areas of high water stress, which will likely displace anywhere between 24 million and 700 million people as conditions become increasingly unlivable. [43] Because the majority of Africa remains dependent on an agricultural lifestyle and 80 to 90 % of all families in rural Africa rely upon producing their own food, water scarcity translates to a loss of food security. [44]

- **Land Deprivation**

  Soil fertility has been used up and there has been a decline in agricultural yields due to intensive farming techniques that have been done over the years.

- **Climate Change**

  Climate change and global warming are occurring at a more prominent rate than ever before. As weather patterns change, rising temperatures due to climate change will lead to a high risk in diminished food supply due to the damages from the heat. [45]

- **Agricultural Diseases**

  Diseases affecting livestock or crops can have devastating effects on food availability especially if there are no contingency plans in place.

- **Politics**

  While drought and other naturally occurring events may trigger famine conditions, it is government action or inaction that determines its severity, and often, even whether or not a famine will occur. The government often neglects subsistence farmers and rural areas in general. The more remote and underdeveloped the area, the less likely the government will be to effectively meet its needs. Many agrarian policies, especially the pricing of agricultural commodities, discriminate against rural areas. Dictators and warlords have used food as a political weapon, rewarding supporters while denying food supplies to areas that oppose their rule. Governments with strong tendencies towards kleptocracy can undermine food security even when harvests are good. When government monopolizes trade, farmers may find that they are free to grow cash crops for export, but under penalty of law only able to sell their farm products to government buyers at prices far below the world market price. The government then is free to sell their product on the world market at full price, pocketing the difference. Many governments, particularly in the U.S., tend to allow large-scale corporations, such as Pepsi and Kraft to control the majority of food sales, which inadvertently negatively affects small-scale farmers. [46] Wars are another huge cause of food insecurity. Conflict often reduces food availability and access when agricultural production and markets are disrupted. Food insecurity can trigger an array of responses, from food riots to revolution. [47] A prime example of this is the current famines that are taking place in Yemen and Syria, due to the conflicts there.

- **Business**

Businesses, in particular, multinational corporations have a very significant impact on food security. The notion of food sovereignty continues to evolve, but it can be broadly understood as a call for people to have a greater capacity to ensure that farming, fishing, labour and land policies are appropriate to the diverse social and ecological contexts in which they occur. [48] It is explicitly critical of the dominant neoliberal economic system. [49] Multinational corporations have the financial resources available to buy up the agricultural resources of impoverished nations, particularly in the tropics. They also have the political clout to convert these resources to the exclusive production of cash crops for sale to industrialized nations outside of the tropics, and in the process, to squeeze the poor off of the more productive lands. [50]

- **Population Growth**

Current UN projections show a continued increase in population in the future (but a steady decline in the population growth rate), with the global population expected to reach 9.8 billion in 2050 and 11.2 billion by 2100. [51] Some analysts have questioned the sustainability of further world population growth, highlighting the growing pressures on the environment, global food supplies, and energy resources. [52]

- F**ossil Fuel Dependency**

While agricultural products have increased over the years, the energy needed to produce a crop has also increased, and at a bigger rate. Green Revolution techniques have also relied heavily on chemical fertilizers and pesticides, many of which are petroleum products. This makes agriculture more reliant on petroleum. [53]

- **Rise in Sea Levels**

Sea levels are also expected to rise with the progression of climate change, which will decrease the amount of available farming land. [54] [Fig-5]

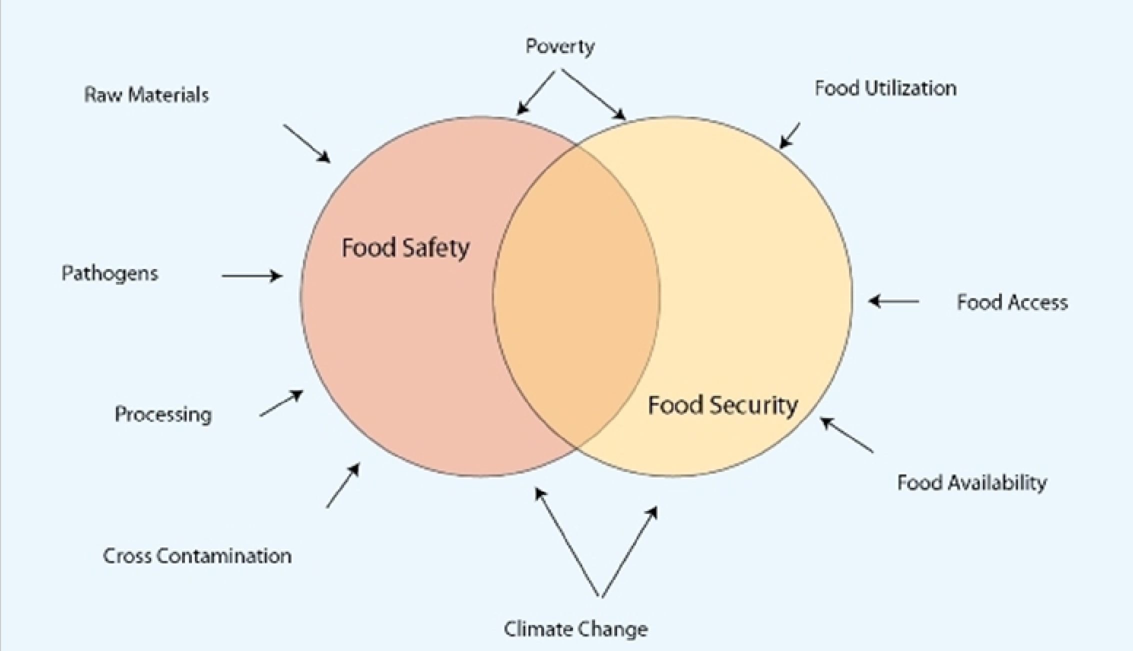
2.3.3 Poverty and Food Security

Food security is highly instrumental to the economic growth and sustainability of any country.
Despite the general worldwide reduction in food insecurity, Africa's food security and nutrition situation is worsening. Africa has been experiencing several episodes of acute food insecurity, causing an immense loss of life and livelihoods over the past decade. African countries have collectively made the least progress toward achieving the Millennium Development Goal of reducing hunger by half by 2015, and currently close to one-third of its population lives in chronic hunger. Many people lack adequate amounts of foods that are rich in the nutrients needed for a healthy and productive life. Nearly 240 million people in Sub-Saharan Africa (SSA), or one person in every four, lack adequate food for a healthy and active life, and record food prices and drought are pushing more people into poverty and hunger. [56]
Increased food production and access are crucial to achieving major nutritional improvement. More foods should be produced that are rich in all the essential micronutrients, available in sufficient quantities and accessible to people all year round. This requires the collaboration of people working in agriculture, fishery, forestry, small animal husbandry, industry, marketing, communications, women's participation, home economics and nutrition. The wide application of proven technologies and approaches in these fields, as well as the development of new concepts, will contribute to solving nutritional problems. The results of research must be transmitted to farmers, and efforts must be made to build on farmers' indigenous knowledge. Consumers, too, need to be involved and educated on how to prevent nutritional deficiencies. [57]
National food production plays a vital role in food security, agro-processing and agro-exports; and hence national self-reliance, employment and foreign exchange. In all aspects.
and considerations, the essential target of national food security is the assurance of readily available food supplies in adequate quantities and quality within the purchasing power of even the poorest consumers all year round – a target that hinges heavily on enhanced production, processing, storage and distribution. [58]

] It is also important to note that food production is not the same as food availability, and that aggregate availability and the ability to acquire food are very different things. [59]
Below is a depiction of the latest UN Sustainable Development Goals (SDGs) and how they relate to nutrition. The 2030 Agenda for Sustainable Development, adopted by all UN Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries – developed and developing – in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. [60] [Fig-6]

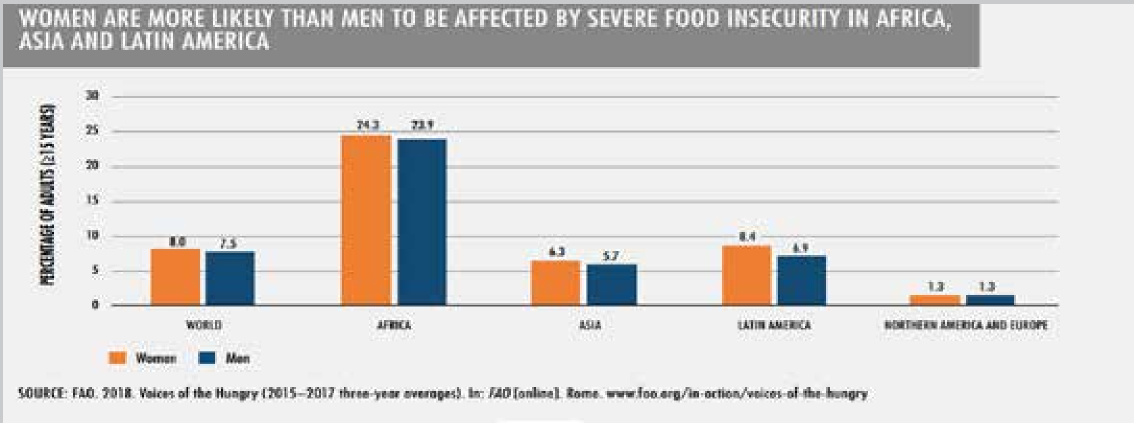
2.3.4 Demographics of Most Vulnerable to Food Security

Unfortunately, food security is both a cause and result of gender inequality. According to many studies, women and girls make up 60% of the world's chronically hungry and little progress has been made in ensuring the equal right to food for women enshrined in the Convention on the Elimination of All Forms of Discrimination Against Women. [61] Women face discrimination both in education and employment opportunities and within the household, where their bargaining power is lower. Women's employment is essential for not only advancing gender equality within the workforce but ensuring a sustainable future with less pressure for high birth rates and net migration. [62] Women tend to be responsible for food preparation and childcare within the family and are more likely to spend their income on food and their children's needs. [63] Data shows that if women had the same access to productive resources as men, women could boost their yields by 20 – 30%; raising the overall agricultural output in developing countries by 2.5 to 4%. While those are rough estimates, the benefit of closing the gender gap on agricultural productivity cannot be denied. [64] [Tab-5,6,7]

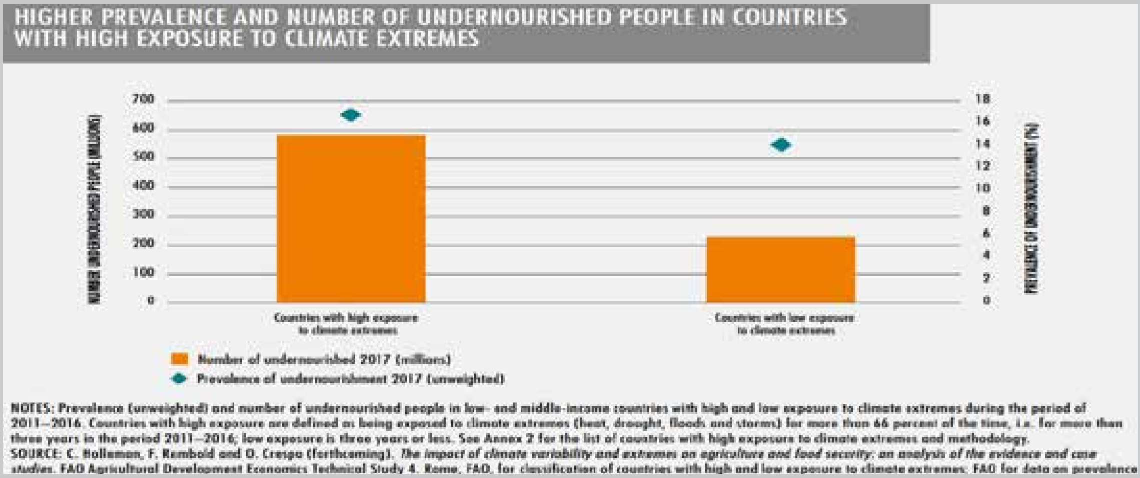


[Fig-5] Interrelationship of Food Safety and Food Security [55]

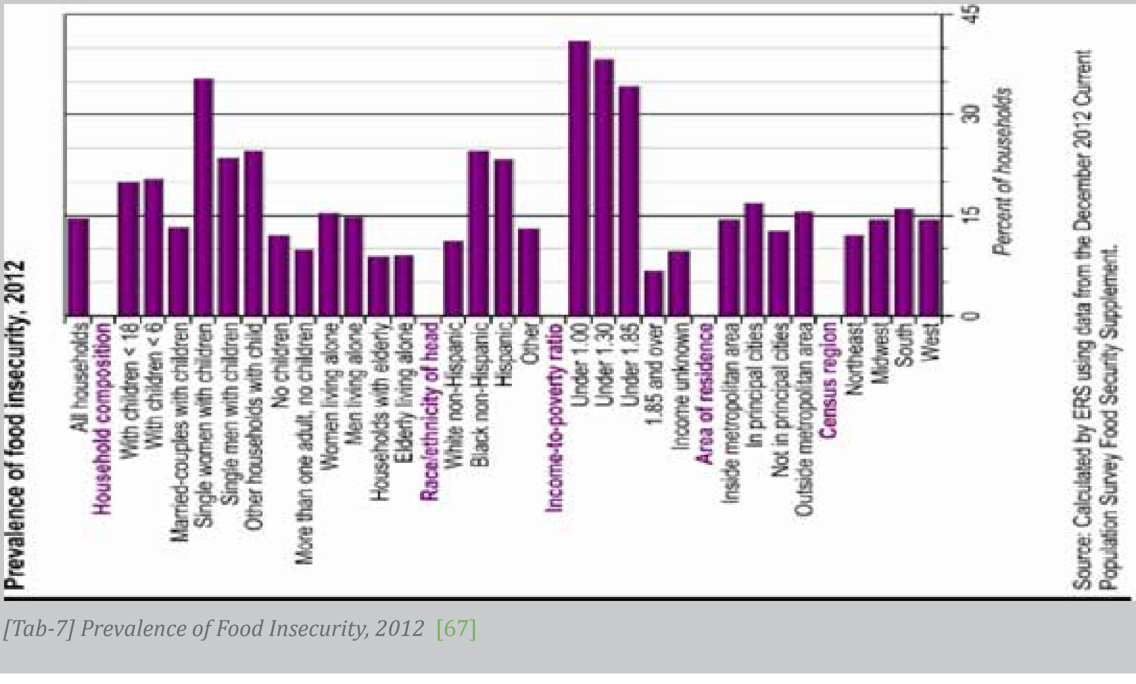
[Fig-6] Nutrition: Essential to Achieve the Sustainable Development Goals [60]



[Tab-5] Prevalence of Women to Men Affected by Severe Food Insecurity in Africa, Asia and Latin America [65]



[Tab-6] Prevalence and Number of Undernourished People in Countries with High Exposure to Climate Extremes [66]



[Tab-7] Prevalence of Food Insecurity, 2012 [67]

2.4 Education in Developing Countrie

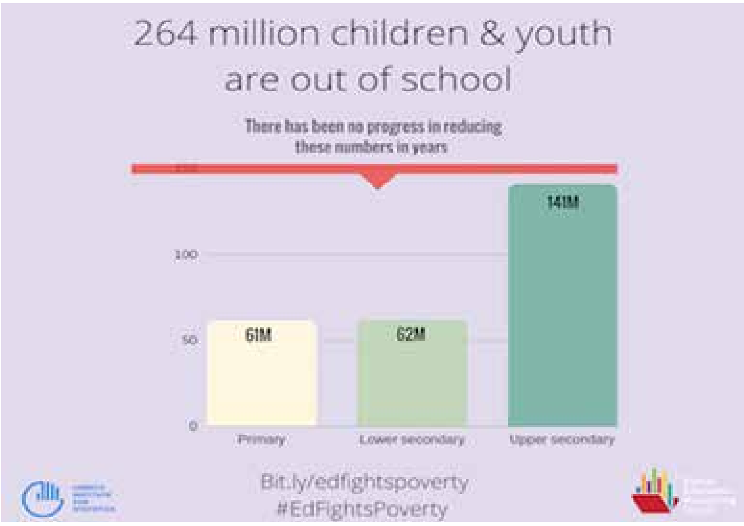
2.4.1 Percentage of Children Who Go to School

According to a new policy paper data from the UNESCO Institute for Statistics, the number of children out of school includes 61 million children of primary school age, 62 million of lower secondary school age, and 141 million of upper secondary school age. [71] [Tab-8]
These youth, between the ages of about 15 to 17 years, are four times as likely to be out of school as children of primary school age, and more than twice as likely to be out of school as those of lower secondary school age. The UNESCO Institute for Statistics (UIS) figures confirm that across Sub-Saharan Africa one in every three children, adolescents and youth are out of school – with girls more likely to be excluded than boys. For every 100 boys of primary school age out of school, there are 123 girls denied the right to education.
The new data also highlight a gulf between out-of-school rates in the world's poorest and richest countries, with an upper-secondary out-of-school rate of 59% across the world's low-income countries, compared to just 6% in high-income countries. [73]

2.4.2 Education in Developing Countries

In an ideal world, everyone should be afforded the opportunity to receive an education. Access to education is the key to economic and social development. When people are given the right tools, they can apply these tools to build a more successful future. Poverty tends to be more frequent in countries where education is less developed. Schooling is one of the strongest predictors of economic well-being. It is a powerful driver of development and one of the strongest instruments for reducing poverty and improving health, gender equality, peace, and stability. Developing countries have made tremendous progress in getting children into the classroom and the majority of children worldwide are now in primary school. Nevertheless, some 264 million children are still not in primary and

secondary school, and hundreds of millions of children cannot read or write, despite having attended school. [68] They are thwarted by poverty, discrimination, armed conflict, emergencies and the effects of climate change. [69]
Education has large, consistent returns in terms of income and reduces inequality. For individuals, it promotes employment, earnings, health, and poverty reduction. For societies, it drives long-term economic growth, spurs innovation, strengthens institutions, and fosters social cohesion. Globally, there is a 9% increase in hourly earnings for one extra year of schooling. Indeed, making smart and effective investments in people is critical to develop the human capital that will end extreme poverty. [70]



[Tab-8] Number of Children Out of School Globally [72]

2.4.3 Reasons Preventing Children Access to Education in Developing Countries

- A lack of funding for education – Global donor support for education is decreasing.

- Having no teacher, or having an untrained teacher – Globally, the UN estimates that 69 million new teachers are required to achieve universal primary and secondary education by 2030.

- No Classroom – Children in many countries in Sub-Saharan Africa are often squeezed into overcrowded classrooms, classrooms that are falling apart, or are learning outside.

- Lack of Learning Materials – Workbooks, exercise sheets, readers and other core materials to help students learn their lessons are in short supply. Teachers also need materials to help prepare their lessons, share with their students, and guide their lessons.

- Exclusion of Children with Disabilities – Despite the fact that education is a universal human right, being denied access to school is common for the world's 93 million children with disabilities. In some of the world's poorest countries, up to 95% of children with disabilities are out of school.

- Being the Wrong Gender – Poverty forces many families to choose which of their children to send to school. Girls often miss out due to belief that there is less value in educating a girl than a boy.

- Living in a country in conflict or at risk of conflict – There are many casualties in any war, and education systems are often destroyed. In 2017, around 50 million children were living in countries affected by conflicts, with 27 million of them out of school, according to UNICEF. Conflict prevents governments from functioning, teachers and students often flee their homes, and continuity of learning is greatly disrupted. In total, 75 million children have had their education disrupted by conflict or crisis, including natural disasters that destroy schools and the environment around them.

- Distance from home to school – For many children around the world, a walk to school of up to three hours in each direction is not uncommon. This is just too much for many children, particularly those children with a disability, those suffering from malnutrition or illness, or those who are required to work around the household.

- Hunger and Poor Nutrition – Being severely malnourished, to the point that it impacts brain development, can be the same as losing four grades of schooling. Around 171 million children in developing countries are stunted by hunger by the time they reach age five. Stunting can affect a child's cognitive abilities as well as their focus and concentration in school.

- The Expense of Education – The Universal Declaration of Human Rights makes clear that every child has the right to a free basic education, so that poverty and lack of money should not be a barrier to schooling. However, in many countries in Africa, while education is theoretically free, in practice 'informal fees' see parents forced to pay for 'compulsory items' like uniforms, books, pens, extra lessons, exam fees or funds to support the school buildings. In other places, the lack of functioning public (government) schools means that parents have no choice but to send their children to private schools that, even if they are 'low fee,' are unaffordable for the poorest families who risk making themselves destitute in their efforts to get their children better lives through education. [74] [75]

2.4.4 School Facilities and Impact of Infrastructure on Educational Quality

Empirical evidence indicates that there is a direct relationship between school infrastructure and educational performance, and that investments in educational infrastructure contribute to improving the quality of education and the economic performance of countries. The quality of classroom conditions and school facilities can be measured using a number of variables, i.e. lighting, ventilation, color, sound, temperature, and safety.
According to the experts, adequate school facilities must comply with the following parameters:

- Comfort for students, teachers, and administrators: spaces for teachers and students, with an adequate temperature, ventilation, and lighting, with water, electricity, and Internet services, as well as sanitary services and the respective drainage of sewage waters.

- Spaces for the development of rehearsals and practices such as libraries, and natural sciences, information technology, physics and chemistry labs.

- Spaces for the development of talents and entertainment, sports, and culture. [76]

59 % of children in Africa do not have access to secondary education. While the majority are attending primary schools, classroom conditions vary across the continent, and there is lack of basic facilities across most countries (basic sanitation and electricity) and overcrowded classrooms.

Availability of electricity is of vital importance to help facilitate schools' activities and overall significantly improves learning environments. It avoids unnecessary cancellation of lessons due to ill-lit classrooms and allows ventilation and use of computers and internet. Availability of sanitation facilities improves the learning environment and pupils' health, boosts school attendance and achievement and promotes gender equality. Lack of fresh water and sanitation is one of the reasons why pupils, and especially girls in many developing countries, opt out of schools. [77]
Therefore, there is a critical need to construct better facilities for children, in particular, structures that have good thermal conditions (fresh air, ventilation, air conditioning) and that have access to electricity and sanitation. Below are some maps indicating the percentage of children who attend schools with no electricity. [Fig-7]

Studies have shown that investments to improve school infrastructure has a strong effect on the educational quality at least in the following three dimensions: [78]

- 1. Attendance and completion of academic cycles. According to UNESCO, the school drop-out rate in Latin America is 17%, and greater in rural areas. Several studies have found that the physical conditions of school buildings positively affect school completion and cycle completion rates, and increase registration. For example, in Peru, the World Bank found that investments in school facilities had a very significant positive effect on students' attendance rates. [79]

- 2. Teacher motivation. Evidence in Bangladesh, Ecuador, India, Indonesia, Peru, and Uganda indicates that teachers in schools with good infrastructure have, on average, 10% less absenteeism than teachers in schools with deficient infrastructure. In fact, the study found that infrastructure had a greater effect on reducing absenteeism than teacher salaries or the effect of the administrative tolerance for absences.

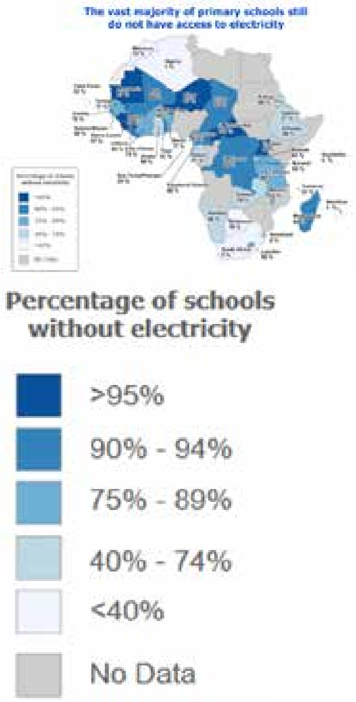
- 3. Learning results. Studies carried out in the United States, such as the one conducted by 21st Century School Fund in 2010, found positive results which are statistically significant between school infrastructure and standardized tests to measure learning processes in many parts of the country. With lower student socio-economic levels, the results were higher. [80] [Fig-8,9,10]

Poor quality of education remains endemic in developing countries. UNESCO reports that 250 million children are functionally illiterate and innumerate despite 50% of them having spent at least four years in school. Similarly, in India, more than half of all grade five students' reading ability stands at a grade two level.

Teacher qualifications and attendance is equally problematic with less than 75% of primary school teachers in developing countries being trained according to national standards. [82] Along the same lines, reports claim that teachers from rural schools in Kenya were absent 20% of the time; while, in Zambia and Pakistan, teachers were absent, respectively, 18 and 10% of the time. [83]

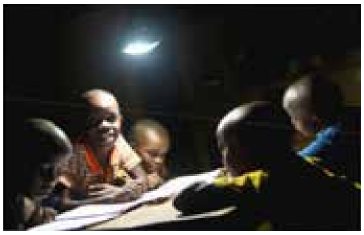
Other supply-side concerns such as overcrowded classrooms, lack of teaching material, and poor infrastructure are also obstacles for good learning environments. In Sub-Saharan Africa, the rapid increase in school enrollment rates accompanied by low teacher

[Fig-7] School in Orissa, India. Photo by Imran Kilinç

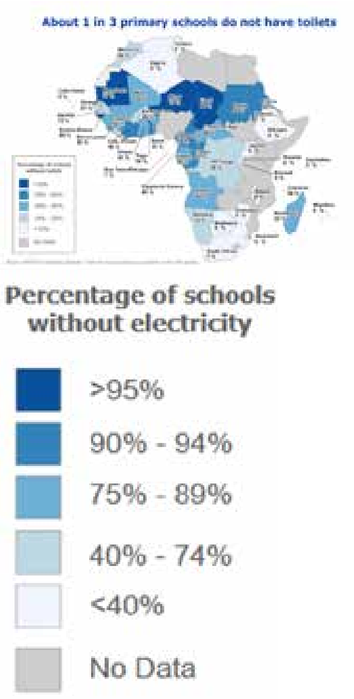


[Fig-8] Source: UNESCO Institute for Statistics [81]

The vista majority of primary schools still do no have access to electricity About 1/3 primary school do not have toilets.



[Fig-9] Children in School with Minimal Lighting Facilities Source: UNESCO Institute for Statistics [83]



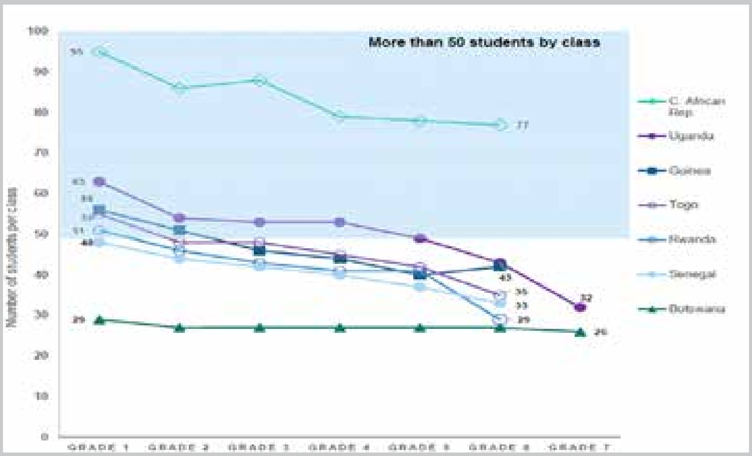
[Fig-10] Source: UNESCO Institute for Statistics [82]

- About 1 in 3 primary school do not have toilets
- Half of primary schools do not have drinking water

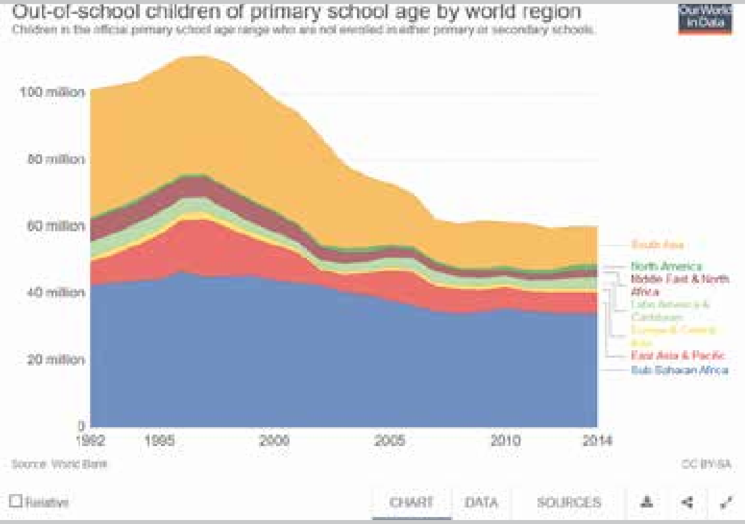
recruitment means that the pupil-teacher ratios in primary education is now exceeding 40:1. Demand-side factors such as discriminatory social norms, group incentive dynamics, and intertemporal choices can also influence the utilization of education services. [84] [Fig-11][Tab-9]

In many developing countries, the government may lack sufficient resources to provide educational services or be administratively incapable of channeling resources to the schools that need them. Government-financed schools may exist in urban areas but not in rural areas or may vary greatly in quality. Or publicly financed schools may be a low priority if the country's economic and political elites send their children to private schools. Public resources may be diverted from primary education to institutions of higher education that serve the governing elite or shifted out of education altogether and into other projects. [85] [Fig-12,13,14]

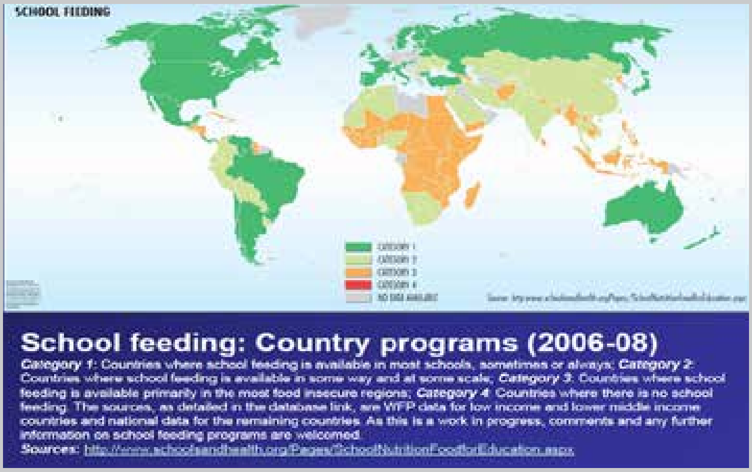
Poor and insufficient school infrastructure negatively impacts student learning and schooling outcomes. Myriad factors have contributed to an infrastructure gap in the education sectorin many countries – rapid increases in enrollments, poor maintenance and aging capital stocks, rural to urban migration, and inefficient government planning and school construction to name a few. By some estimates, as many as 10 million classrooms and $100 billion in infrastructure investment are needed just to support the achievement of the Millennium Development Goals (MDGs): 1) which means, the overall global challenges are far bigger. 2) Meeting the challenges may require increased funding, but it will also require improved efficiency of infrastructure provision.



[Tab-9] Early Grades are Most Critical, but Most Overcrowded Source: UNESCO Institute for Statistics [82]



[Tab-10] Decline of the Absolute Number of Out-of-School Children in Primary School Age [88]



[Fig-15] Categories of School Feeding Country Programs [96]

[Fig-11] School with Access to Water. Source: UNESCO Institute for Statistics [82]

[Fig-12] A Teacher Leads a Class at a Primary School in Burundi's Capital, Bujumbura. [86]
Photo by Thomas Mukoya/Reuters

[Fig-13] A Student Stands in the Ruins of his Former Classroom which was Destroyed in June 2015. At the Aal Okab School in Saada, Yemen. Students Now Attend Lessons in UNICEF Tents Nearby. Photo by Clarke for UNOCHA [89]

[Fig-14] Photo by Marcus Prior, World Food Programme

2.5 School Feeding Programs

According to the United Nations World Food Programme, 66 million primary school age children go hungry every day, with 23 million hungry children in Africa alone. Furthermore, 80% of these 66 million children are concentrated within just 20 countries. Additionally, 75 million school-age children (55% of them girls) do not attend school, with 47% of them living in Sub-Saharan Africa. [90] Thus, the need to reduce hunger while increasing school enrollment in these children is evident, and school feeding programs have been developed to target this multifaceted problem.
School feeding programs have been defined by the World Bank as "targeted social safety nets that provide both educational and health benefits to the most vulnerable children, thereby increasing enrollment rates, reducing absenteeism, and improving food security at the household level." [91] Beyond improvements in access to food, school feeding programs also have a positive impact on nutritional status, gender equity, and educational status, each of which contributes to improving overall levels of country and human development.
School feeding in low-income countries often starts through funding by international organizations or national governments through various programs. Some governments, however, first started school-feeding programs on their own and then requested the help of these organizations and programs. Additionally, many countries are no longer dependent on foreign assistance and have reshaped their school feeding programs to be country-led and self-supported.
About 368 million children in the world are fed daily at school by national governments. [92]The number of children receiving school meals is often lowest in countries where the need is the greatest: in low-income countries, only 18% of primary schoolchildren receive school meals, while in lower-middle-income countries the figure is 49%. [93]School feeding is just one facet of school health initiatives, as other programs may include de-worming, HIV/AIDS prevention and education, and life and health skills education. Overall, school feeding programs have been shown to directly increase the educational and nutritional status of recipient children, and indirectly impact the economic and social lives of themselves and their family. [94]

2.5.1 Types of School Feeding Programs

School feeding programs distribute food to children in two ways – through on-site meals and take-home rations. On-site meals are foods that are distributed to children while at school during morning and afternoon meal and snack times. They could include a bowl of porridge or nutrient-fortified crackers. Take-home rations are a collection of basic food items, such as a bag of rice and a bottle of cooking oil, which may be sent home and given to the families of children who regularly attend school. [95]While the food distributed at schools can come from anywhere in the world, an increasing number of countries and organizations are opting to expand what is called "home-grown school feeding," which requires that provided food is produced and purchased within a country to the greatest extent possible. These programs provide an opportunity for children to receive improved nutrition and educational opportunities while also allowing smallholder farmers to benefit from access to a market with stable, structured, and predictable demand. The New Partnership for Africa's Development (NEPAD) guided governments in Sub-Saharan Africa to include home-grown school feeding as a critical intervention for the food security facet of the Comprehensive Africa Agriculture Development Programme (CAADP). Several countries, including Côte d'Ivoire, Ghana, Kenya, Mali and Nigeria are currently taking part in home-grown school feeding programs. [97]

2.5.2 Stages (of Involvement) in School Feedings

According to the International Food Policy Research Institute, there are five stages of school feeding. The first stage includes school feeding programs that rely mostly on external funding and implementation, while the last stage includes school feeding programs that rely mostly on internal government funding and implementation. Countries that are within the first stage include Afghanistan and Sudan, where country governments are unable to lead school feeding programs. Countries that are within the fifth stage include Chile and India, which have functional, country-led school feeding programs. Countries that are in the middle of the stages, such as Kenya and Ecuador may have some but not all of the governmental policies, financial capacities, or institutional capacities to operate school feeding programs without external funding or implementation. [98][Fig-15]

2.6 International Organizations for Food Security and Education

2.6.1 Agencies Working with Food Security

There are several international organizations that work to combat hunger and increase food security around the world. The following agencies are the largest and most impactful.

1. United Nations Food and Agriculture Organization (FAO)
The Food and Agriculture Organization of the United Nations leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO's mandate is to raise levels of nutrition, improve agricultural productivity, better the lives of rural populations and contribute to the growth of the world economy. FAO is the largest of the UN agencies. It was established in 1945 and its headquarters is in Rome, Italy. [99]

2. The United Nations World Food Programme (WFP)
The World Food Programme aims to eradicate hunger and malnutrition. It is the world's largest humanitarian agency. Every year, the programme feeds almost 80 million people in around 75 countries. Through food security analysis and monitoring, WFP provides actionable food security information for each country in which it works. By combining traditional assessment methods with advanced and emerging technologies, they are able to identify food insecure populations around the world, and to establish the underlying causes of food insecurity.

WFP works closely with national governments, UN partners and NGOs to inform the policies and programs adopted to fight hunger in different circumstances. WFP's food security analysts do a wide range of face-to-face assessments, including 'baseline' assessments (also known as Comprehensive Food Security and Vulnerability Analyses, or CFSVA) and emergency food security assessments (EFSA) in rapid and slow-onset emergencies such as hurricanes, floods, droughts and conflict situations. EFSA reports provide a snapshot of the food security situation and are updated on a regular basis. [100]

3. The World Bank Group (WBG)

The World Bank Group is part of the United Nations system and has a formal relationship agreement with the UN, but retains its independence. The WBG comprises a group of five legally separate but affiliated institutions: the International Bank for Reconstruction and Development (IBRD), the International Finance Corporation (IFC), the International Development Association (IDA), the Multilateral Investment Guarantee Agency (MIGA), and the International Centre for Settlement of Investment Disputes (ICSID). It is a vital source of financial and technical assistance to developing countries around the world. Its mission is to fight poverty with passion and professionalism for lasting results and to help people help themselves and their environment by providing resources, sharing knowledge, building capacity and forging partnerships in the public and private sectors. The WBG headquarters are located in Washington, D.C. [101]

4. The United Nations International Fund for Agricultural Development (IFAD)

The International Fund for Agricultural Development was established as an international financial institution in 1977, as one of the major outcomes of the 1974 World Food Conference and a response to the situation in the Sahel. It is dedicated to eradicating rural poverty in developing countries. Its headquarters are in Rome, Italy. Since 1978, they have provided $18.5 billion USD in grants and low-interest loans to projects that have reached about 464 million people. [102]

5. Consultative Group on International Agricultural Research (CGIAR)

The 16 international agricultural research centers of the Consultative Group on International Agricultural Research (CGIAR) fully recognize the strengths and limitations of many aspects of the traditional food production systems. They are actively contributing to research on the development of improved systems to optimize productivity, to ensure sustainability and to maximize the efficiency of utilization of inputs, within the constraints of smaller producers. [103]

- **Bioversity International**

Bioversity is one of the major research centers in the CGIAR. They are a global research-for-development organization. Their vision is to have agricultural biodiversity nourish people and sustain the planet.

They deliver scientific evidence, management practices and policy options to use and safeguard agricultural and tree biodiversity to attain sustainable global food and nutrition security. They work with partners in low-income countries in different regions where agricultural and tree biodiversity can contribute to improved nutrition, resilience, productivity and climate change adaptation. [104]

2.6.2 Agencies Working With Education

There are a multitude of organizations that work to improve children's access to education. Three of the largest and most renowned are UNICEF, UNESCO and the World Bank.

1. United Nations International Children's Emergency Fund (UNICEF)

In cooperation with governments and non-governmental organizations (NGOs), UNICEF saves and protects the world's most vulnerable children, working to ensure child rights and providing health care, immunizations, nutrition, access to safe water and sanitation services, basic education, protection and emergency relief. Their work is carried out in 192 countries through country programs and national committees, collaborating with partners to develop educational systems that provide the world's most disadvantaged children with learning opportunities that change their lives and the lives of their children. [105]

2. United Nations Educational, Scientific and Cultural Organization (UNESCO)

UNESCO seeks to build peace through international cooperation in education, the sciences and culture. Its programs contribute to the achievement of the Sustainable Development Goals defined in Agenda 2030. UNESCO develops educational tools to help people live as global citizens free of hate and intolerance. They work to provide each child and citizen access to quality education. By promoting cultural heritage and the equal dignity of all cultures, UNESCO strengthens bonds among nations and fosters scientific programs and policies as platforms for development and cooperation. They stand up for freedom of expression, as a fundamental right and a key condition for democracy and development. Serving as a laboratory of ideas, their programs help countries adopt international standards and manage programs that foster the free flow of ideas and knowledge sharing. [106]

3. The World Bank Group (WBG)

The World Bank Group works with countries around the globe to develop and improve their education systems. Their approach is inclusive and focused, understanding the needs of governments and working with them to ensure learning for all. Their projects, analytical work and technical assistance span from early childhood education through higher education, with the goal of ensuring that all children can realize the promise of education.

Ensuring access requires also strengthening quality, while considering the specific needs of the most vulnerable, such as children living in fragile and conflicted affected areas, refugees, children with disabilities and those who are vulnerable because they are female or from a marginalized community. They also consider adult learning a real need, whether it is to gain basic literacy and numeracy skills or for job training and business skills. They continue to develop innovative approaches in identifying, supporting and developing the best routes for delivering learning for all. In several countries, WBG funds are helping to attract much larger resources from governments, as well as other development partners, resulting in streamlined education programs and lower transaction costs for governments. Since 2000, the WBG has invested almost $50 billion in education in over 120 countries, highlighting the importance of education for the achievement of their twin goals, ending extreme poverty and boosting shared prosperity. [107]

Together with UNICEF, the WBG launched the Early Childhood Development Action Network (ECDAN) in 2016, which is bringing together governments, development partners, civil society, parliamentarians, and the private sector to increase investments in early childhood development. [108]

[Fig-16] Students in class at a primary school in Bingerville, a commune of Côte d'Ivoire's capital, Abidjan. In Côte d'Ivoire, less than seven children out of ten go to primary school.

UNICEF distributes school kits to children and supports the Ministry of Education by building schools and training teachers. Photo by Dejongh, UNICEF [108]

- **Global Partnership for Education**

In 2002, the WBG was instrumental in creating the multi-donor Global Partnership for Education (GPE), an important partner in basic education. Efforts to better coordinate education financing from GPE and the International Development Association (IDA), the WBG's fund for the poorest countries, are underway. GPE functions to create a global effort to reduce educational inequality with a focus on the poorest countries. They are the only international effort with a particular focus on supporting countries' efforts to educate their youth from primary through secondary education. Main goals of the partnership include providing educational access to each child, ensuring each child masters basic numeracy and literacy skills, increasing the ability for governments to provide quality education for all, and providing a safe space for all children to learn in. They are a partnership of donor and developing countries but the developing countries shape their own educational strategy based upon their personal priorities. When constructing these priorities, GPE serves to support and facilitate access to financial and technical resources. Successes of GPE include helping nearly 22 million children get to school, equipping 52,600 classrooms and training 300,000 teachers. [109][Fig-16]

2.6.3 Agencies Working With School Feeding

1. United Nations World Food Programme (WFP)

The World Food Programme aims to eradicate hunger and malnutrition. It is the world's largest humanitarian agency. Every year, the programme feeds almost 80 million people in around 75 countries. In terms of external funding and implementation, WFP is the world's leading provider of school feeding program financial contributions and program development. It currently provides school feeding resources to an average of 22 million children in school, about half of whom are girls, across 70 countries. The total financial contribution for these programs is almost $500 million per year. Many governments work alongside WFP in school-feeding programs, though in countries where the government is non-functional or corrupt, WFP may work on its own or with other non-governmental organizations. The World Food Programme has estimated that $3.2 billion is needed each year to feed the 66 million school-age children around the globe, an amount of $50 per child. [110]

WFP has been working with governments around the world for over 45 years but is shifting from a food aid organization to food assistance organization, working to move away from "individual, isolated projects to more strategic and comprehensive approaches." [111] To foster government ownership of school meals, WFP has implemented eight quality standards that guide the design and implementation of sustainable school meal programs:

- A strategy for sustainability
- A national policy framework
- Stable funding and budgeting
- Needs-based, cost-effective quality program design
- Strong institutional arrangements for implementation, monitoring, and accountability
- Strategy for local production and sourcing
- Strong partnerships
- Inter-sector coordination, and community participation and ownership [112]

WFP argues that high-energy biscuits, fortified with nutrients, provide energy and other essential nutrients to help children learn better and grow healthy through improved nutrition. School feedings provide obvious benefits in terms of education and nutrition, but they can also be a way to boost local agriculture.

In 2017, WFP implemented or supported school feeding programs in 71 countries. It directly provided school meals to 18.3 million children in 60 countries. It also built the capacities of 65 governments, which led to improved national school feeding programs for another 39 million children. In Syria, 660,000 school children received a meal, snack or take-home food from WFP.

Food is procured locally when possible. In 46 countries, school feeding programs are linked to local smallholder farm production, combining nutritional and educational benefits with a positive impact on local economies. Partnering with civil society, school feeding programs can help build trust in national education systems and foster social inclusion. In Tunisia, where the national school feeding program reaches 240,000 children in 2,500 schools, local youths are employed as caterers, ensuring local ownership.

Programs can be tailored to target specific groups of children, including those forced into child labor, or those whose lives have been affected by HIV/AIDS. They can also prevent early marriage for girls and child pregnancies, and help girls access better paid jobs through education.

With this one single policy, the World Food Programme (WFP)'s **Home Grown School Feeding** initiative is striving to dramatically improve the nutrition of schoolchildren and boost local economies. This innovative approach links school feeding programs with local smallholder farmers to provide millions of schoolchildren in 46 countries with food that is safe, diverse, nutritious, and above all local.

This policy benefits both the local farmers, as the schools are able to provide local farmers with a predictable outlet for their products, leading to a stable income, more investments and higher productivity; and the children, who get to enjoy healthy, diversified food. This makes it more likely that they will stay in school, perform better and improve their adult job prospects. At the community level, Home Grown School Feeding initiatives promote nutrition education and better eating habits, and encourage the diversification of production with a special emphasis on local farm products. Community involvement, in turn, enhances the sustainability of programs.

Building on its expertise in food security, procurement, logistics and school feeding, WFP works with governments to develop national policies and strategies for Home Grown School Feeding programs, and to design or implement such initiatives directly where needed. Local producers' contribution to the programs, and the benefits they derive from them, depend on context-specific factors – the range of actors involved, the size and precise objectives of the program, the quantity and type of foodstuffs required, and other purchasing and contractual variables. This is why models can be different from country to country, and sometimes within the same national boundaries. 46 countries have WFP-supported home-grown school feeding programs. [113]

"Every day more than 66 million children go to school hungry and, in many countries, fewer girls attend school than boys. Research shows that providing in-school meals, mid-morning snacks, and take-home rations through school feeding programs can alleviate short-term hunger, increase children's abilities to concentrate, learn, perform specific tasks, and has been linked to an increase in the enrollment of girls. These effects seem to be greater among children who are also chronically undernourished, usually the poorest children.

Low-income countries are expanding school feeding, because these programs help push them closer to reaching the Millennium Development Goals (MDGs) by drawing more children, especially young girls, into the classroom. If these programs provide micronutrients such as iron, iodine, vitamin A, B-vitamins, and zinc through fortified foods and are combined with other school health interventions such as deworming, there may be additional benefits for children's cognitive abilities and educational achievement. Additionally, school feeding programs are increasingly being viewed as a potential safety net and as a social support measure that helps keep children in school. In response to the shocks of the global food, fuel, and financial crises, countries looked to implement school feeding as a rapidly scalable social protection mechanism, able to provide more than 10% of household expenditures.

The successful transition of school feeding programs to sustainable country-owned programs depends on the integration of school feeding into national policies, especially education sector plans, national financing, and national implementation capacity. Local procurement of food is a possible means to achieve sustainable programs, often known as "Home Grown School Feeding." It is critical that long-term sustainability is incorporated into programs from their inception, and that programs are continuously revisited as they evolve. As more and more governments seek to expand these programs in their countries, it is important to have more opportunities for knowledge sharing among developing countries that focus on ways to improve the procurement of locally available nutritious foods and compare best practices." [114]

Challenges for school feeding programs can range from their high operational costs to the need to build the capacity to procure food locally.

In right are some photographs of school feeding programs that WFP helps to implement across the world. [Fig-17,18]

[Fig-17] Children in Myanmar With High-Energy Biscuits. Provided by UN WFP. Photograph by Philip McKinney/WFP

Fig-18] At a School in Tete Provice, Mozambique, Mothers Volunteer to Cook Meals for Students. Photograph by Molly Slotznick/WFP

- **Globally, approximately 368 million children – about one in five – get a daily meal at school.**

School feeding provides obvious benefits in terms of education and nutrition, but it can also be a way to boost local agriculture, WFP argues. In northern Mozambique, beans, oil, maize flour and salt are provided for the students' meals, along with cooking pots and materials for a warehouse that fathers in the community helped to build. [115]

2. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO)

FAO recognizes that schools are an ideal setting to support the nutrition and development of children and youth. Schools reach children at an age when food and health habits are being formed.

They also influence families, the school community and can be a channel for wider community participation. Promoting better diets and nutrition through schools can create health and wellbeing benefits that extend beyond the classroom to households and communities. Linking school meal programs to local food production can increase community involvement, strengthen and diversify local food systems, and improve the livelihoods of smallholder farmers. FAO works with governments to leverage schools' potential through school food and nutrition programs, supporting the Sustainable Development Goals (SDGs) of food security, nutrition, education, health, decent work and economic growth and reduced inequalities for everyone.

Food and nutrition education help children and youth practice food choices that support both human and environmental health. Linking school meal programs to local production strengthens the connection between nutrition, agriculture and local economies. The whole school community, including children, families, teachers, school staff, vendors, foodservice staff, civil society, government staff and local farmers, have an active role and responsibility in supporting healthier school meals and food environments. Home-Grown School Feeding can improve the livelihoods of smallholders and the community, while providing safe and nutritious food to school children.

- **Food and Nutrition Education**

FAO promotes a "whole school" approach to nutrition education, which involves all factors that influence children's diets, including their families, teachers, school staff, smallholder farmers, foodservice staff, food vendors and others. Educational lessons and practical activities that complement each other are integral parts of effective school-based nutrition education. Classroom lessons are paired with hands-on opportunities for students to experience, practice and be actively involved in learning about food, diets and health.

This comprehensive approach helps create positive attitudes and skills and helps pave the way for carrying healthy habits beyond school and into adulthood. School-based food and nutrition education programs encourage and empower children and their communities to take ownership of their own diets and food choices and become agents of change in local food systems.

School gardens are also commonly used as a learning platform. FAO encourages and supports countries to promote school gardens with educational goals to help students, school staff and families make the connection between growing food and good diets, develop life skills and increase environmental awareness. FAO supports governments in developing nutrition standards for school meals and policies for a healthier school food environment. The food environment shapes how foods are made accessible, affordable, desirable and convenient for children and communities. Healthy school food environments enable and encourage school communities (children, families, school staff, etc.) to make food choices that lead to better diets and well-being.

FAO supports governments in developing Home-Grown School Feeding (HGSF) programs, which purchase safe, diverse and nutritious food for school meals from local smallholder farmers. This approach aims at delivering healthy meals to children, while at the same time, stimulating local agriculture and economies.

HGSF programs augment the positive impact of regular school feeding programs and promote multiple benefits. This approach can improve the access and availability of nutritious food for both schoolchildren and local communities; value local dietary habits and ingredients; support the adoption agro-ecological and/or climate-sensitive agriculture practices; create business opportunities for smallholder farmers and other vulnerable producers (including women, youth, and members of traditional communities).

HGSF programs provide an opportunity to benefit local farmers, producers and processors by generating a stable, structured and predictable demand for their products, building the market and benefiting the wider local economy. They enable the development of nutrition-sensitive and inclusive value chains that play an important role in shaping and strengthening sustainable local and national food systems.

- **Policy, Legal and Institutional Environment**

To be elective, school food and nutrition programs need to be supported by national policies, regulations and institutions. At the Second International Conference on Nutrition (ICN2), governments committed to develop policies, programs and initiatives to ensure healthy diets throughout life, including school food and nutrition programs. To achieve these objectives, FAO supports countries in adopting the right policies and legal and institutional frameworks to implement comprehensive school food and nutrition programs, with human-rights based approaches that bring together the diverse sectors, such as agriculture, health, education and social protection that are related to school feeding. [116]

2.7 Food Conservation and Storage

[Fig-19] Photo by Freya Morales/ UNDP

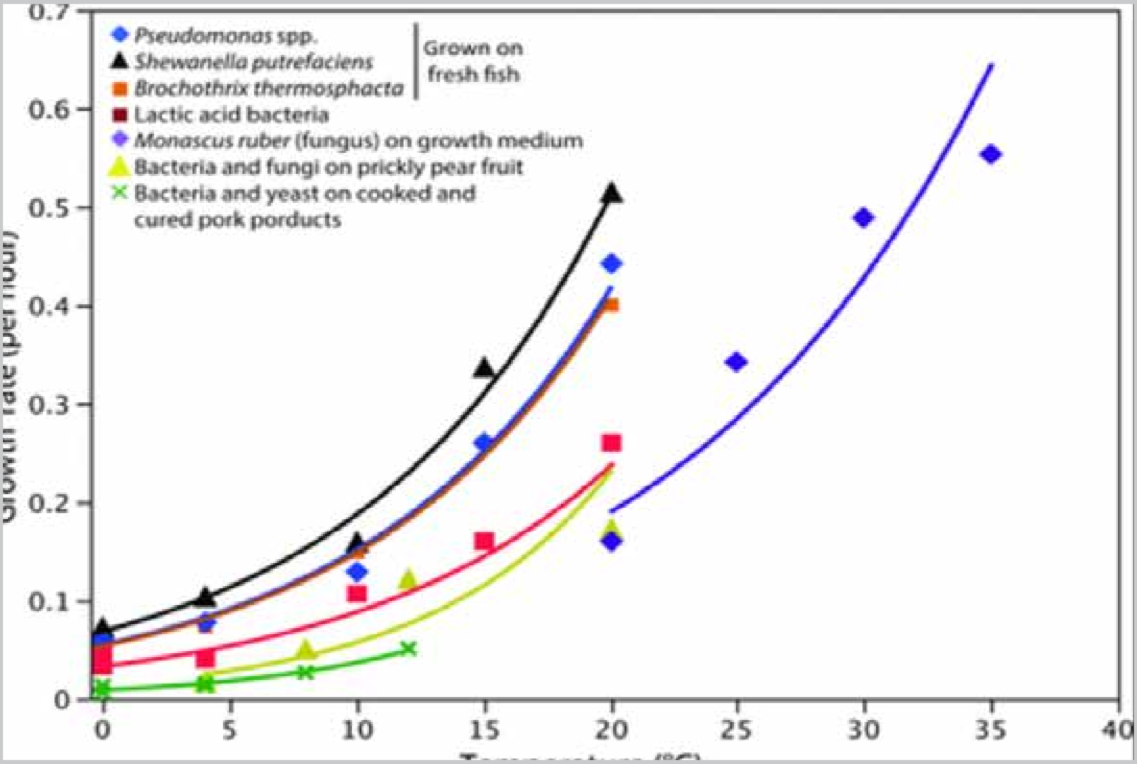
2.7.1 Food Spoilage and Storage

Although often taken for granted by consumers in modern, developed societies, maintaining a reliable food supply has always played a major role in the history of our species. In addressing issues of food security and sustainability, agricultural production has garnered considerable attention from researchers and policymakers [117,118] but food spoilage, storage, and transport have received much less attention. The inescapable realities that food production is inherently patchy in both time and space and that all food inevitably spoils have led to numerous technological innovations in preservation, storage, and transportation, but their roles in shaping human history have arguably received insufficient attention from sustainability scholars and human ecologists. [119][Fig-19]
Along with a number of UN agencies (FAO, ILO and ITC), regional governments, local entrepreneurs and farmers' cooperatives, are working to introduce sustainable practices when growing agricultural products, and to reduce crop losses and boost smallholder farmers' profits. The program will build an agro-processing facility that will help with these efforts and provide training on food security, new business planning and produce diversification.
Reducing food waste will be key to achieving the Sustainable Development Goals related to food security and nutrition. The UNDP has recently started to train young farmers, teaching them about conservation, and sustainable tomato preparation and distribution techniques. In addition to practical training and technical supervision, they are also exploring potential international markets where they could sell some of these local tomatoes. [120]
The chart above shows the temperature-dependent growth rates of various microbes involved in food spoilage. An exponential curve has been fitted to the data points for each culture using ordinary least squares. [Tab-11]

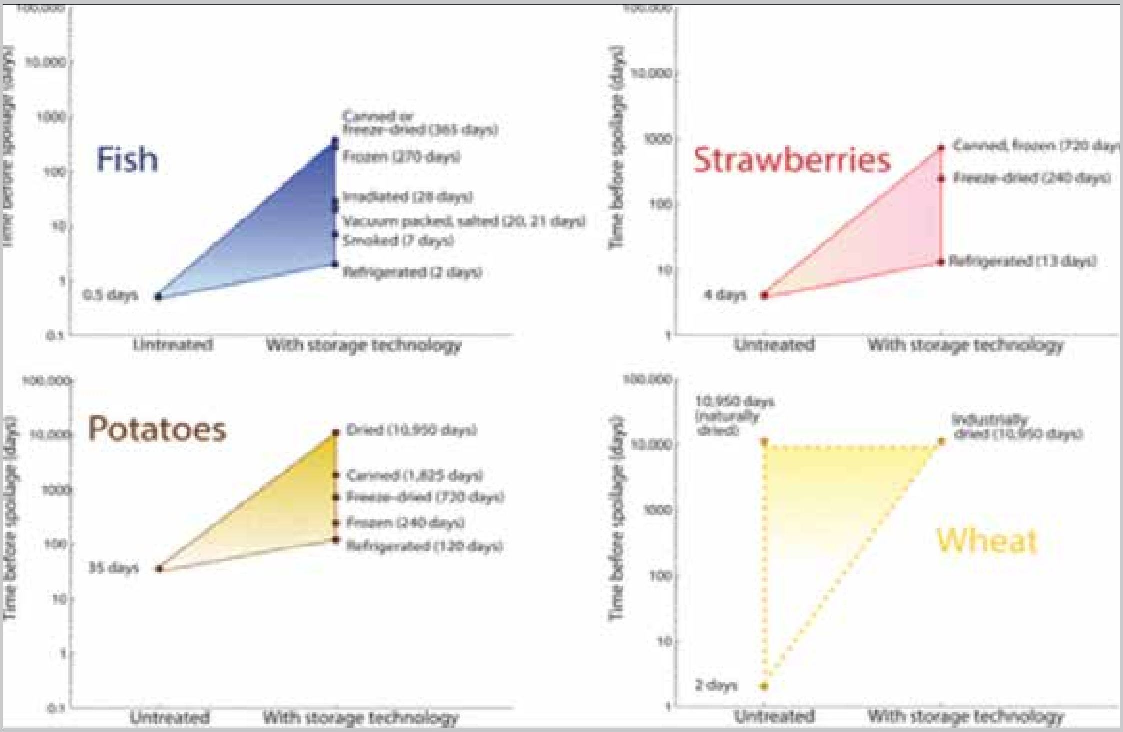
Depending on temperature, water content, nutrient composition, and the presence or absence of antibiotic compounds, foodstuffs remain nutritious and nontoxic to humans for periods from a few hours to many years. Food scientists use shelf life to quantify the length of time a food can be stored and remain suitable for human consumption or commercial sale, but the storage times can vary by orders of magnitude depending on the identity of the foodstuff, environmental conditions, and methods of preservation (figure below). At one extreme, fresh fish, meat, shellfish, and many fruits and vegetables can be stored for only a few days, even under refrigeration. Foods that naturally contain little water, an unbalanced nutritional composition, or possess antibiotic compounds or protective layers last longer. At the other extreme, dry seeds and frozen foods can be stored for years. [Tab-12]
Below is a chart comparing the conservation time of various staple farm products, when left in room temperature, refrigerated and frozen. Of course, the actual degrees of room temperature will depend on the outside climate, and the spoilage will occur sooner in warm climate areas versus cooler climates.
Having a general overview of the length of times food products last can help us better understand how to implement food storage strategies to best fit our needs. [Tab-13]

Avoiding Food Spoilage

“Spoilage of food constitutes a large percentage of the factors affecting food security in many African countries. Foods spoil because of many reasons, of which the most important are lack of storage facilities. Where available, the required power to make them functional could be lacking. Infection of food with pathogenic microorganisms could also threaten public health if such food has not been adequately processed. This is a challenge that could be resolved by taking appropriate steps. The government could provide necessary assistance in the form of credit facilities to small-scale food processors to enable them to procure storage systems that would prevent



[Tab-11] Growth Rates of Bacteria with Rise in Temperature [121]



[Tab-12] Shelf Life of Representative Food Items, With and Without the Use of Storage Technology. The time to spoilage varies widely over untreated food, from less than a day in fish to over a month in root vegetables such as potatoes to many years in grains such as wheat that have been naturally dried on the stalk. The increase in shelf life that results from the use of storage technology varies widely by the technology. [122]

Time to Spoilage (days)	Storage Technology	Food	Energy [kcal/kg]	Data Sources
0.5	Raw	Fish	0	(FAO 2014)
270	Freezing	Fish	4200	(Man et al. 1994)
2	Refrigeration	Fish		(Roberts and Graham 2013)
1	Raw	Beef	0	(Djenane et al. 2003)
168	Freezing	Beef	3299	(Man et al. 1994)
10	Refrigeration	Beef		(Djenane et al. 2003)
2	Raw	Spinach	0	(Daw and Hicks 2001)
5	Refrigeration	Spinach		(USDA 2011)
187	Freezing	Spinach	3467	(Fu and Labuza 1997)
4	Raw	Strawberries	0	(Dong et al. 2013)
720	Freezing	Strawberries	8175	(Ayala-Zavala et al. 2004)
13	Refrigeration	Strawberries		(Ayala-Zavala et al. 2004)
21	Raw	Apples	0	(Saftner 1999)
56	Refrigeration	Apples		(Gregerson 2009)
270	Freezing	Carrots	4200	(Caillet et al. 2006)
14	Refrigeration	Carrots		(Roberts and Graham)
240	Freezing	Potatoes	3935	(EatByDate 2012a)
35	Raw	Potatoes	0	(Khan et al. 1986)
120	Refrigeration	Potatoes		(EatByDate 2012a)
365	Freezing	Corn	5039	(Kendall and Dimond)
20	Refrigeration	Milk		(Roberts and Graham)
90	Freezing	Milk	2610	(Kendall and Dimond)
120	Fermentation (Cheese)	Cheese	188.69	
1	Raw	Poultry	0	(Heinz and Hautzinger 2010)
720	Freezing	Poultry	8175	(Cosby et al. 1999)
12	Refrigeration	Poultry		(Cosby et al. 1999)
1	Raw	Pork	0	(Heinz and Hautzinger 2010)
180	Freezing	Pork	3405	(Roberts and Graham)
5	Refrigeration	Pork		(Roberts and Graham)
2	Raw	Lettuce		(Daw and Hicks 2001)
7	Refrigeration	Lettuce		(Arvanitoyannis et al. 2008)
10	Raw	Peaches		(Toğrul and Arslan 2004)
5	Refrigeration	Peaches		(Roberts and Graham)
720	Freezing	Peaches	8175	(Toğrul and Arslan 2004)
7	Raw	Citrus	0	(FreshDirect)
14	Refrigeration	Citrus		(Roberts and Graham)
5	Raw	Mangos	0	(McCurdy et al. 2009)
7	Raw	Grapefruit	0	(McCurdy et al. 2009)
10950	Drying	Wheat	91	(SurvivalAcres)
2	Raw	Wheat	0	(McNeill et al. 2008)
7	Raw	Onion	0	(Roberts and Graham)
60	Refrigeration	Onion		(Faridah et al. 2006)
10950	Drying	Rice		(SurvivalAcres)
90	Raw	Egg	0	(Editors 1977)

[Tab-13] Food Storage Comparison Chart **[123]**

food spoilage. An enabling environment should also be provided, especially in terms of power availability to maintain such storage systems." [124]

Throughout history, people have discovered various ways of conserving food to avoid spoilage and potential illnesses from consumption. Below are some of the various techniques used:

- **Pickling –** is the process of soaking food in a solution containing salt, acid or alcohol. It can be used with most foods, including fruits, vegetables, meats, seafood, legumes and eggs.
- **Curing** - is similar to pickling, but uses salt, acid and/or nitrites. It is used for meat and fish, but also fruits and vegetables, such as cabbage (in the making of sauerkraut), cucumber (in the making of pickles) and olives.
- **Smoking** – first used by early humans for meats, and cheese, having discovered that compounds present in wood smoke have anti-microbial actions that prevent the growth of organisms that cause spoilage. This process is still popular today, particularly to add interesting and distinctive flavors to foods. [125] [126]
- **Drying** – is the act of simply leaving foods out in the sun and wind to dry out, and is probably one of the earliest forms of food preservation. Because most disease-causing organisms require a moist environment in which to survive and multiply, drying is a natural technique for preventing spoilage. Vacuum drying is a form of preservation in which a food is placed in a large container from which air is removed. Vacuum drying is biologically desirable, as some enzymes that cause oxidation of foods become active during normal air drying.
- **Salting** – occurs when salt binds with water molecules and thus acts as a dehydrating agent in foods. The value of adding salt to foods for preservation has been well known for centuries. [127]
- **Fermentation** – is a naturally occurring chemical reaction by which a natural food is converted into another form by pathogens. It is a process in which food "goes bad", but results in the formation of an edible product. Perhaps the best example of such a food is cheese. Early humans discovered that the spoilage of milk can be controlled to produce this new product. [128]
- **Bread** – is another food product made by the process of fermentation. Flour, water, sugar, milk and other raw materials are mixed together with yeast and then baked. The addition of yeast brings about the fermentation of sugars present in the mixture, resulting in the formation of a product that will remain

edible much longer than the original raw materials used in the bread-making process. [129]

- **Iru** – is a locust bean by extensive hydrolysis of its indigestible components by microbial enzymes fermentation, improving the flavor and texture of raw agricultural produce, and imparting a desirable sour taste to many foods. The locust bean's name might seem deceiving – while only distantly related to beans, it is actually a tree. It is indigenous to the savannah regions of Africa, and most commonly found in the band stretching from Senegal to Uganda. [130]
- **Roasting** – is another method of preserving food and it affects desirable sensory qualities, enhancing palatability and reducing anti-nutritional factors.
- **Blanching** – is a method of food preservation that inactivates plant enzymes and minimizes oxidative changes, leading to deterioration in sensory and nutritional qualities such as enzymatic browning. It is done by heating food in hot water in a pot for various durations. [131]
- **Cellaring** – is the process of storing foods in a temperature-, humidity- and light-controlled environment. It can be used with many foods, especially vegetables, grains and nuts, as well as fermented foods and dry-cured meats. There are many different methods for cellaring food, all of which are relatively easy to do. This could be used to extend the shelf-life of the produce and make them available for a longer period of time. [132]

7.7.2 Challenges of Conserving Produce in Developing Countries

The use of simple but effective on- and off-farm storage facilities and agro-processing technology should be promoted to add value to products and increase their shelf-life. The Strategic Grain Reserve Scheme should be modernized, strengthened and upgraded to a National Food Reserve Program, which will enable it to handle all staples and essential food products. This will help in attainment of national food security goal. It is also crucial to promote and develop agro-processing in the various African countries for the evolution of virile agro-allied industries and rural micro-enterprises. [133]

Shortcomings of Traditional Preservative Techniques and Solutions for African Countries

The various traditional preservative techniques discussed above have several shortcomings which often make food security unattainable in African countries. These shortcomings include: low productivity, poor and non-uniform quality of products, poor shelf-life of products from the methods, etc. The adoption of modern preservative techniques such as freezing, canning or bottling and irradiation would remove the challenges of traditional food preservative techniques and enhance food availability and food security in Africa.

- **Freezing** – is an effective form of food preservation because the pathogens that cause food spoilage are killed or do not grow very rapidly at reduced temperatures. The process is less effective in food preservation than thermal techniques such as boiling because pathogens are more likely to be able to survive cold temperatures than hot temperatures. A number of factors are involved in the selection of the best approach to the freezing of foods, including the temperature to be used, the rate at which freezing is to take place, and the actual method used to freeze the food. [134]
- **Canning or bottling** – is a process that requires canning equipment and the ability to use a heat source to raise the temperature of the food to destroy spoilage and pathogenic microorganisms. Foods preserved by this method are sealed in a closed container, such as a can, glass or bottle; such foods can be stored for up to a year. The cost of canning or bottling can be expensive after purchasing the equipment and using heating fuel. There is also a risk of severe food poisoning if the process is not followed properly, especially the case of low-acid foods such as vegetables and meat. [135]
- **Irradiation** – is a recent method of preserving food, which has been thoroughly researched over the past few decades, and is recognized as a safe and wholesome method. It has the potential to disinfect both dried food to storage losses and fruits and vegetables to meet quarantine requirements for export trade. Irradiation can decontaminate foods from pathogenic organisms and thus provide safe food to the consumer. [136]
- Improving Farm Product Storage
  In some developing countries, an estimated 25% of all food produced is never consumed by humans. Instead, it spoils or is eat-

en by insects, rats and other pests. Measures to correct this situation can be taken in fields, households, shops and warehouses. These may include:

- a. Controlling rats by trapping, poison, rat-proofing grain stores, etc.
- b. Controlling insects by using insecticides, better food stores and airtight food containers
- c. Controlling fungi and food rot by storage of food in as dry a state as possible and by use of better containers
- d. Controlling birds by destruction, especially in millet and wheat areas
- Protective measures against monkeys, baboons, porcupines, e. wild pigs and other destructive animals, even elephants [137]

Storage of Roots, Tubers, Bananas and Plantains

Roots, tubers, bananas and plantains account for some 40% of total food supplies (in terms of food energy) for about one-half of the population of Sub-Saharan Africa, where overall food supplies are at very low levels. Production could be increased to meet future needs, although consumption has been tending to decline. The decline has been associated with increased urbanization, which does not favor highly perishable and labor-intensive products. Further research into converting starchy roots into less perishable and more convenient food products for the urban population could help reverse these trends.

Fresh cassava tubers, once harvested, deteriorate rapidly and therefore are best left unharvested until needed. Sweet potatoes and yams, however, exhibit a period of dormancy, and their storage life can thus be extended by curing. Alternatively, yams, cocoyams and cassava may be stored in underground pits after harvesting. In a study in south-eastern Ghana, 91% of farmers surveyed practiced underground storage of unharvested cassava, but only 5% of the respondent households used this technique for yams. [138]

2.7.3 How Locally Grown Food Improves Food Security

Changes in food-storage technologies accelerated with the transition from agricultural to industrial–technological societies. The concentration of an ever-increasing proportion of the population in cities means that an ever-decreasing proportion of farmers and fishers must produce all the food and thus, larger harvest areas and longer supply lines are needed. The increasing distance between harvesters and consumers means that spoilage must be prevented for longer periods, typically days to weeks, because food is transported over distances of hundreds to thousands of kilometers. [139] Therefore, having food grown locally results in a number of benefits for the local community. It shortens the supply chain, and decreases transportation time and energy, it improves nutrition of local consumers, who will be able to have a larger amount of fresh produce, and decreases energy spent on various food conserving techniques outlined above.

2.7.4 Agricultural Productivity

Agricultural productivity is measured as the ratio of agricultural outputs to agricultural inputs. It is not generally used to express the power of agriculture in a particular region to produce farm products without regard to whether that power is due to the bounty of nature or to the efforts of the man. [140]

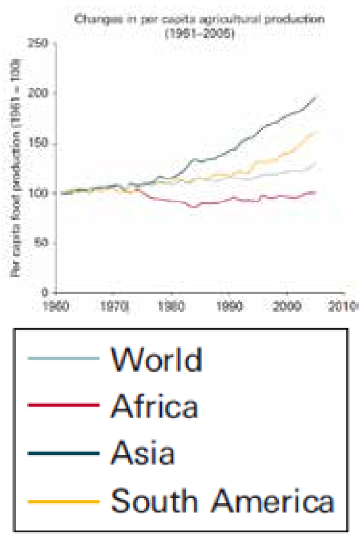
Aside from providing more food, increasing the productivity of farms affects the region's prospects for growth and competitiveness on the agricultural market, income distribution and savings, and labor migration. An increase in a region's agricultural productivity implies a more efficient distribution of scarce resources.

Agriculture is inextricably linked to the environment. Natural resources must be managed, conserved, and protected. If producers are to meet the demands of a growing global population over the long term. Farmland with healthy soils and adequate water are the basic inputs that, when enhanced by technology and good management practices, produce affordable food, fiber, and fuel. Although some agricultural activities and practices can degrade environmental quality, a growing body of work suggests that managing agriculture as an ecosystem can achieve both strong agricultural production and a healthy environment.

Agricultural systems will be pushed significantly harder in the coming years. Fifty to 100% more food will be needed by 2050 to meet the needs of a population that will top nine billion. Production will need to be dramatically increased while safeguarding biodiversity, conserving habitat, and reducing the environmental footprint of agriculture. Obstacles to meeting this challenge are significant, numerous, and varied. In addition to increasing water scarcity and the expected effects of global climate. [141,142]

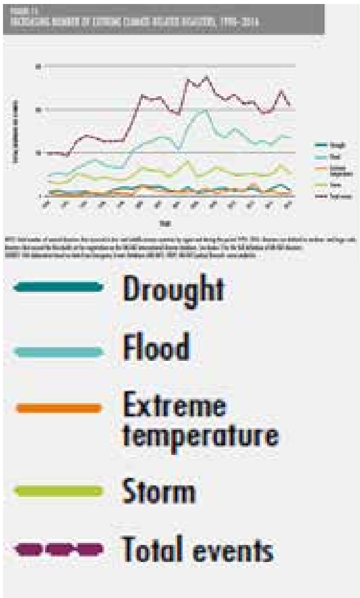
"Intensification and concentrating food production in the most productive regions may appear the most efficient way to use the land. However, risks to food security may be increased, because supply chains become more vulnerable and because of pollution. Loss of crop diversity, decline of pollinators and increased vulnerability of monocultures to diseases are additional stress factors. On the other hand, regional or local self-sufficiency and the reliance on extensive farming systems would require more cultivated land at the expense of natural habitats. It is not enough to only increase total food production. The food must also be locally available, affordable and meet quality standards. The distribution channels and trade patterns are key in this respect." [143]

Adeyeye from the Department of Food Science and Technology at the University of Agriculture, Nigeria recommends "the use of simple but effective on- and off-farm storage facilities and agro-processing technology should be promoted to add value to products and increase their shelf-life. The Strategic Grain Reserve Scheme should be modernized, strengthened and upgraded to a National Food Reserve Programme in many African countries, which will enable it to handle all staples and essential food products." [144]



[Tab-14] Changes in Per Capita Agricultural Production, 1961 to 2005 [145]

2.8 How Passive Architecture Can Lower Greenhouse Emissions and Have a Positive Effect on Climate Change



[Tab-15] Increasing Number of Extreme Climate-Related Disasters, 1990-2016 [146]

Though warming has not been uniform across the planet, the upward trend in the globally averaged temperature shows that more areas are warming than cooling. Since 1880, surface temperature has risen at an average pace of 0.13°F (0.07°C) every 10 years for a net warming of 1.69°F (0.94°C) through 2016. Over this 137-year period, average temperature over land areas has warmed faster than ocean temperatures: 0.18°F (0.10°C) per decade compared to 0.11°F (0.06°C) per decade. [147][Tab-15]

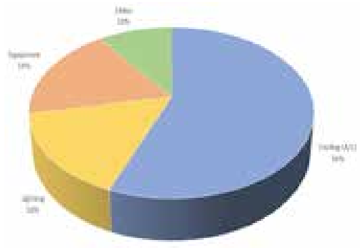
2.8.1 The Amount of Electricity Used in Hot Climates for Air Conditioning

The building sector is one of the main energy consumers in the world, contributing around 40% of the total energy consumption, with HVAC systems being the biggest contributors. [148] In tropical and subtropical areas, cooling in buildings has become essential for thermal comfort, particularly in public buildings such as offices, supermarkets, sport centers, etc., where energy consumption accounts for over 50% of building's energy demands. It is also becoming increasingly popular in European countries, due to increasing level of thermal insulation and air tightness, and more recently to frequent warm weather patterns.

Similarly, concern over building energy consumption is being raised in developing countries, such as South East Asia. For example, in Indonesia and Malaysia, buildings account for a large proportion of total electricity sales; and energy consumption increased constantly due to heavily subsidized electricity, population growth and economic prosperity. Energy subsidies in Indonesia in the last ten years have contributed about 80% of total budget for social programs.

There is therefore a strong interest to utilize energy resources as efficiently as possible. It is predicted that by 2020, the energy consumption in South East Asian countries will exceed that of developed countries. The most dominant air conditioning system for buildings in the market today is the mechanical vapor-compression

refrigeration system. This technology is quite popular because it has good stability in performance, long life cycle, reasonable energy performance, and is easy to control. However, it consumes large amounts of electricity. Today, the use of mechanical HVAC systems is widespread. Moreover, in hot and humid climates, the AC systems have to deal with indoor air humidity by reducing the air temperature below its dew point, resulting in even lower than the required temperature, thus furthering the waste of energy. Therefore, it is important to understand the cooling requirement for tropical climates to determine the most efficient approach to provide comfort in buildings. [149]
"In hot dry climates, it is estimated that almost half of the urban peak load of energy consumption is used to satisfy air-conditioning cooling demands in summer time. Since the urbanization rate in developing countries – like the case in Egypt – is rising rapidly, the pressure placed on energy resources to satisfy inhabitants' indoor comfort requirements is consequently increasing too." [150] These numbers only provide further support for the need to implement sustainable architectural strategies for future building projects."[Tab-16]



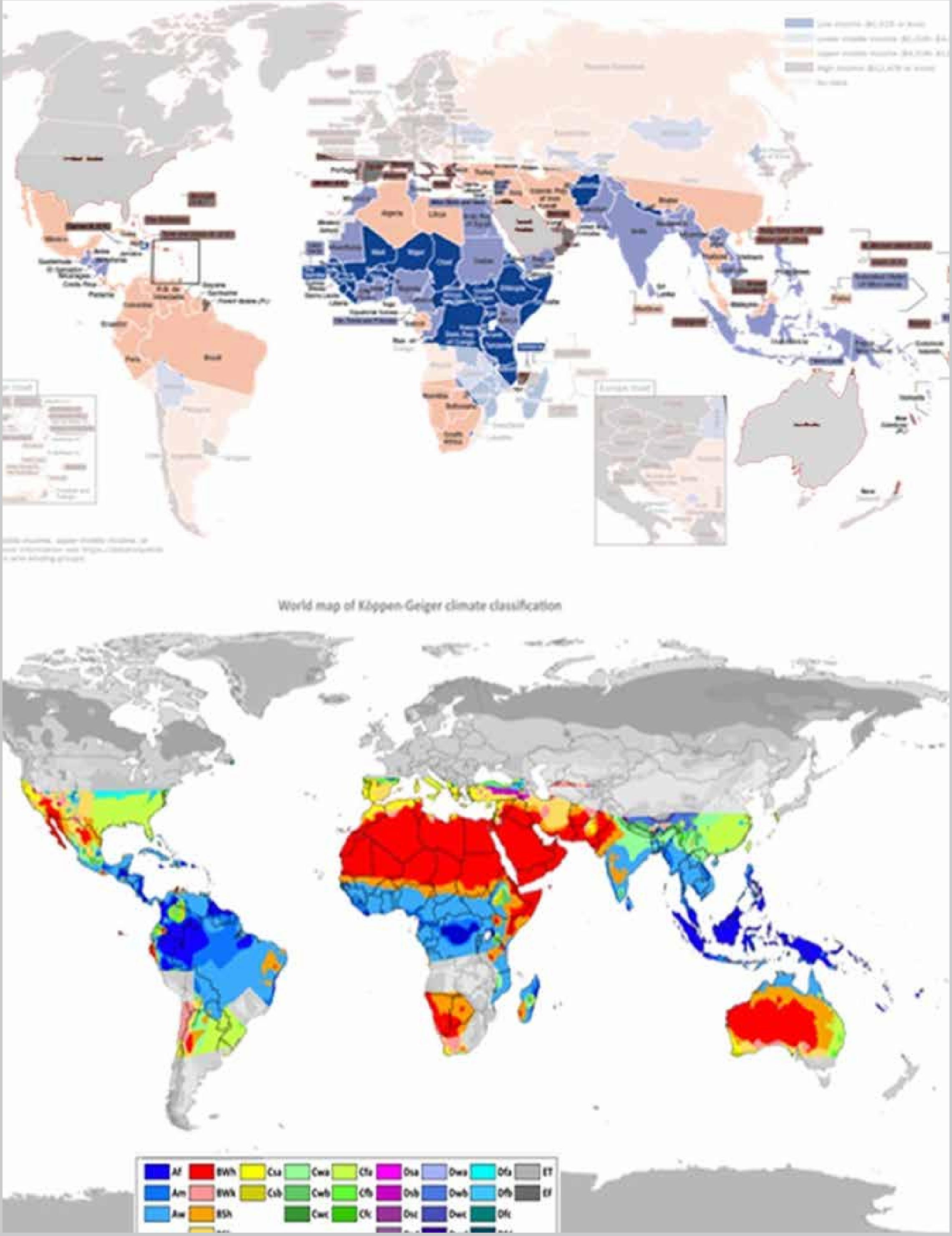
[Tab-16]Typical building energy consumption in tropical countries 56% Colling A/C (R. Boukhanouf, University of Nottingham)[151]

2.9 How Sustainable Architecture Can Provide Concrete Solutions to These Problems

Sustainable architecture is architecture that seeks to minimize the negative environmental impact of buildings by efficiency and moderation in the use of materials, energy, and the ecosystem at large. It uses a conscious approach to energy and ecological conservation in the design of the built environment. [152]
If we look at the map of low-income developing countries and the map of hot climate areas in the world below, we can see that around 70% of low-income countries are mostly located in hot areas. [Fig-20]
Upon conclusion of this research, we will see how some of the main social problems prevalent in hot climate countries, outlined in this chapter, can be addressed though architectural, climate and natural ventilation solutions. We have tried to understand, from the point of view of international humanitarian organizations, what major problems these countries face, and will now look into how sustainable architecture could provide concrete solutions to these problems. Solutions include spending low energy by using passive cooling systems, and implementing traditional architecture mixed with new modern passive technologies.

2.9.1 What Kind of Passive Architecture Could Be Useful for Developing Countries with Hot Climates?

People that are living in hot climate countries usually have low incomes, and many do not have access to electricity. Because of lack of resources and technology, governments in developing countries rarely pay enough attention to largescale modern sustainable architectural projects.
As will be discussed in the following chapters, creating a proper thermal comfort is essential for the health and well-being of the general population. Also, as warm climates induce more perspiration in people, there is an even higher need to have regular access to water supplies, in order to keep hydrated.
Due to lack of funding for electricity and other essential facilities, incorporating a passive cooling system that does not require elec-



[Fig-20] Low-Income Vs. Warm Climate Countries [153] [154]

tricity, using the local natural resources available with simple architectural methods, without any intervention of high technology, we can construct structures that achieve a good level of thermal comfort with minimal costs.

All of the studies about traditional and vernacular passive cooling architecture that will be presented in the following chapters, like wind-towers, wind-boxes, thermal mass, use of lower temperature underground floors, cupolas, solar chimneys, and other passive cooling techniques that do not require electricity, could be the best solution to achieving better thermal comforts in these communities. If international organizations and state governments can begin to implement programs that educate the local communities on the various architectural strategies that incorporate natural cooling and ventilation systems, and combine them with their local traditional architectural styles, we could make a real sustainable change in the comfort of local communities.

2.10 Conclusion

Among the top UN Sustainable Development Goals for 2030, the top two goals of the 17 listed are No Poverty and Zero Hunger. Other goals include Quality Education, Sustainable Cities and Communities, Responsible Reduction and Consumption, and Climate Action. [155] The sustainable architecture projects proposed in the following chapters can assist in all of these global long-term goals.

As shown above, comparing world maps of hot climate areas with low-income developing countries, we can clearly decipher that the high majority of low income countries are located in hot climate areas. There are a few exceptions – Australia, Israel and Persian Gulf countries. However, the rest are struggling with many issues due to lack of funding and resources. The lowest income hot climate countries are located in Sub-Saharan Africa.

In this chapter, we delved deeply into the issues of poverty, food security, education and the role of some of the world's most important international organizations. We understood that women and children, being the most vulnerable in these hot climate low-income countries, must be better looked after.

Three major issues were analyzed:

- **Low Access to Education and Information**
- **Low Food and Water Security and Health Conditions**
- **Low Income and Opportunity for Employment**

In the end, the types of passive architecture strategies that will be discussed in this dissertation can be used as important tools to address all three of these issues. For example, to construct low budget structures that can create better living conditions in schools, thereby improving education; building sustainable storage faculties that can better conserve farm products, preferably grown locally, for longer periods of time; and other essential buildings in communities, like medical clinics etc. Architecture itself cannot directly combat poverty and hunger, but the techniques proposed in the following chapters can contribute to improving the comfort and health of the local populations by improving food security and education conditions through the construction of schools and storage facilities.

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CHAPTER 3 Wind Behavior and Architecture

3.1 Objective

The main issues that will be explained in this chapter are:

- What is the definition of wind? Why does wind exist on Earth?
- Why are quantity, quality and direction of wind important?
- How and why do we have different types of winds? What are their main factors?
- What is the important fluid physics theory relevant to wind that could be useful for architecture?
- Explain the wind behavior on an urban scale and then relative to architecture to see how different types of architecture could create different wind reactions within the same situation.
- How can electricity be produced by wind?
- How can we estimate wind behavior? What are the software programs that could be used to create a wind behavior simulation in architecture?
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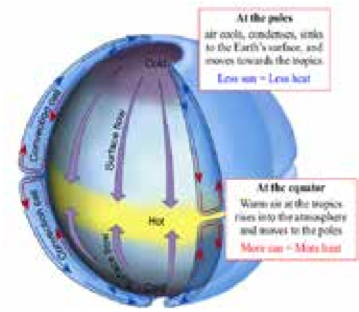
3.2 Wind Definition

"Wind is the perceptible natural movement of air, especially in the form of a current of air blowing from a particular direction." [1]

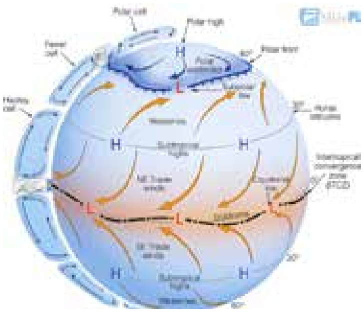
"Wind is one of the most important factors of transferring heat, humidity, dust and pollution on earth. This factor could help human comfort or it could make it unfavorable." [2]

When the weather is warm, wind could be helpful to make us cooler by body-evaporation and convection. On the other hand, if the weather is cold, we try to zip up our jackets or use heavy jackets to block the cold wind from contacting our body. For a sustainable architecture, we need to control or use the wind to create better comfort in buildings and in public spaces. We need qualitative and quantitative information about the wind of the area and also learn some of the aerodynamic behaviors of wind and of the fluid mechanics rules, that all together, will help the designer to profit from wind behavior inside and around the building and use this natural ventilation to cool the environment through a passive way. Wind is also a main source of transportation for seeds and small birds. With time, many things can travel thousands of miles with the wind.

3.3 Winds of the Earth



[Fig-1] Effect of Sun Radiation on Wind Direction on the Earth



[Fig-2] Wind Circulation in Different Latitudes and Earth Spin

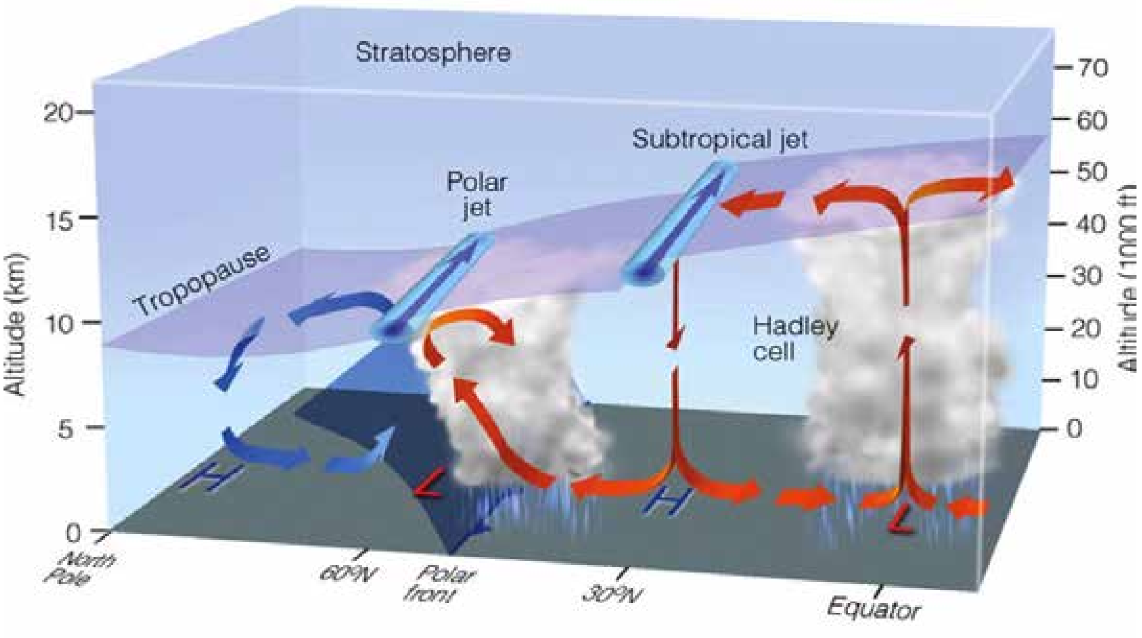
“Wind is caused by the gases of the Earth’s atmosphere moving about in an attempt to equalize pressure; it seems natural to assume that wind would blow outward from areas of high pressure, towards areas of lower pressure. In a perfect world, free from other influences, this would indeed be the case. However, sometimes other factors can cause wind to blow differently than this expected pattern. There are four types of wind balance that creates air movement:

- *Cyclostrophic Balance – Pressure*
- *Gradient Force = Centrifugal Force*
- *Geostrophic Balance – Pressure Gradient Force = Coriolis Force*
- *Gradient Wind Balance – Pressure Gradient Force = Centrifugal + Coriolis Forces*
- *Hydrostatic Balance – Pressure Gradient Force = Gravity”* [3]
-

“Wind is moving air and is caused by differences in air pressure within our atmosphere. Air under high-pressure moves toward areas of low pressure. The greater the difference in pressure, the faster the air flows.” [4] “Wind develops when the sun’s rays unevenly heat the air in the atmosphere. [Fig-1] The majority of heating occurs at the Equator, which receives the most direct rays. Those rays warm the Equator air, which rises and moves north and south to the cooler regions. The air in the northern and southern hemispheres flows into the low-pressure area created at the Equator by the rising hot air. At the same time, the earth is spinning creating a Coriolis force that shifts moving particles, such as the air, to the right in the northern hemisphere and left in the southern hemisphere. The uneven heating and the Coriolis forces together, create the geostrophic winds, which are one kilometer above ground and are the overall prevailing winds in each region. [Fig-2] Geostrophic winds only give a very general idea of the direction of the wind at each latitude. At a given site, the elements of the landscape – hills, valleys, bodies of water, and other obstacles, have a significant effect on winds as high up as 100 meters, although the upper atmosphere winds can pull along the lower winds and give them more power.” [5]

3.3.1 Solar Heating and Atmospheric Circulation

"Circulation system is needed to balance things. As air warms, it expands, becomes less dense and rises up into the atmosphere. In the upper atmosphere, the air cools, condenses, becomes denser, and falls down to the surface. [Fig-3] *This is called convection current. At the Earth's surface, the warm air at the tropics rises into the atmosphere and moves to the poles. Once it reaches the poles, air cools, condenses, sinks to the Earth's surface, and moves towards the tropics."* [6]



[Fig-3]

3.4 Wind Factors

"Winds are commonly classified by their spatial scale, their speed, and the types of forces that cause them, the regions in which they occur, and their effect. Winds have various aspects, an important one being its velocity (V; wind speed); another density of the gas involved; wind energy and wind direction." [7]

[Fig-4] Anemometrograph: Used to Measure Speed and Direction of Wind in H:10M of Synoptic Station

3.4.1 Wind Speed

"In elevated levels of the earth, there is less friction, so air molecules could have more speed to move. However, in certain heights, there is no friction effect, and its speed depends only on wind pressure. Power states;

$$\frac{Vz}{Vz10} = \left(\frac{Z}{Z10}\right)^{\alpha}$$

(α: depends on how much the surface is smooth; 0.11 in large flat lands and 0.36 in the center of large cities with tall buildings, Vz average speed of wind, Z10 height = 10 M, VZ10 is the velocity of win in 10 M height)." [7]

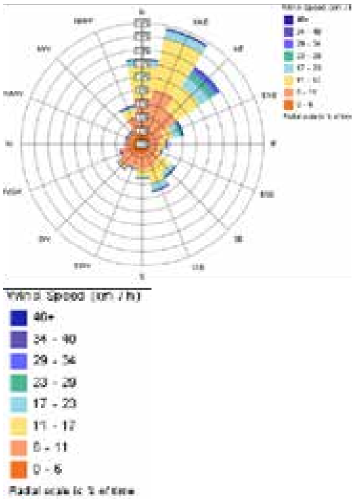
Wind Speed Definition:
"Wind speed is the distance that air molecules move in units of time. For example: M/S or KM/H or Node = Mile/Hour." [8] Anemometrograph [Fig-4] is a tool of synoptic stations that should be assembled in h = 10 M in height and it is used to measure the wind speed.
Wind speed or wind flow velocity, is a fundamental atmospheric quantity caused by air moving from high to low pressure, usually due to changes in temperature. The wind speed increases with height, wind turbines are mounted on high towers, although the height of an actual tower is limited by structural concerns and cost.
Wind Speed Classification (Beaufort Classification)
"The Beaufort scale is an empirical measure that relates wind speed to observed conditions at sea or on land. Its full name is the Beaufort wind force scale. [Tab-1]

The scale was devised in 1805 by the Irish hydrographer Francis, a Royal Navy officer, while serving on the HMS Woolwich. The scale that carries Beaufort's name had a long and complex evolution from the previous work of others (including Daniel Defoe the century before) to when Beaufort was Hydrographer of the Navy in the 1830s, when it was adopted officially and first used during the voyage of HMS Beagle under Captain Robert FitzRoy, later to set up the first Meteorological Office (Met Office) in Britain giving regular weather forecasts. [9] [Tab-2]
The measure was slightly altered some decades later to improve its utility for meteorologists. Today, many countries have abandoned the scale and use metric system based units, m/s or km/h, instead, but the severe weather warnings given to the public are still approximately the same as when the Beaufort scale was used." [10]
There are also other classifications made in Japan, which explain wind classification effects on their surroundings, lake surface and snow. [11] [Tab-3]

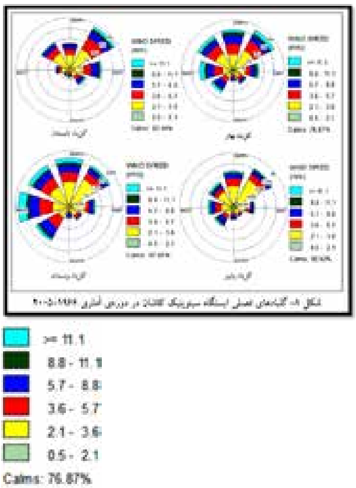
[Tab-1] Beaufort Wind Speed Classification

Beaufort Number	Wind Speed (miles/hour)	Wind Speed (km/hour)	Wind Speed (knots)	Description	Wind Effects on Land
0	< 1	< 1	< 1	Calm	Calm. Smoke rises vertically.
1	1-3	1-5	1-3	Light Air	Wind motion visible in smoke.
2	4-7	6-11	4-6	Light Breeze	Wind felt on exposed skin. Leaves rustle
3	8-12	12-19	7-12	Gentle Breeze	Leaves and smaller twigs in constant motion.
4	13-18	20-28	11-16	Moderate Breeze	Dust and loose paper are raised. Small branches begin to move.
5	19-24	29-38	17-21	Fresh Breeze	Small trees begin to sway.
6	25-31	39-49	22-27	Strong Breeze	Large branches are in motion. Whistling is heard in overhead wires. Umbrella use is difficult.
7	32-38	50-61	28-33	Near Gale	Whole trees in motion. Some difficulty experienced walking into the wind.
8	39-46	62-74	34-40	Gale	Twigs and small branches break from tree Cars veer on road.
9	47-54	75-88	41-47	Strong Gale	Larger branches break from trees. Light structural damage.
10	55-63	89-102	48-55	Storm	Trees broken and uprooted. Considerable structural damage.
11	64-72	103-117	56-63	Violent Storm	Widespread damage to structures and vegetation.
12	> 73	> 117	> 64	Hurricane	Considerable and widespread damage t structures and vegetation. Violence.

[Tab-2]



[Fig-5] Yearly Wind Direction Diagram: Main Direction is NNE and then NE



[Fig-6] Seasonal Wind Directions Diagram of Kashan from 1966 to 2005 (Top-right; Spring, Top-left; Summer, Down-Right; Fall, Down Left; Winter)

3.4.2 Wind Direction

Wind can change in many different directions during the day or even during an hour. It is very important not to have industrial or waste management facilities located in the main wind direction of the surrounding cities, since this can cause more pollution to move there.

Wind Direction Defined

“The direction of the wind is expressed as the direction from which the wind is blowing. For example, easterly winds blow from east to west, while westerly winds blow from west to east.” [12] “Wind direction is measured in degrees clockwise from due north. Consequently, a wind blowing from the north has a wind direction of 0°; a wind blowing from the east has a wind direction of 90°; a wind blowing from the south has a wind direction of 180°; and a wind blowing from the west has a wind direction of 270°. In general, wind directions are measured in units from 0° to 360°, but can alternatively be expressed from -180° to 180°. Winds are named for the direction from which they come, followed by the suffix -erly. For example, winds from the north are called "northerly winds." [13]

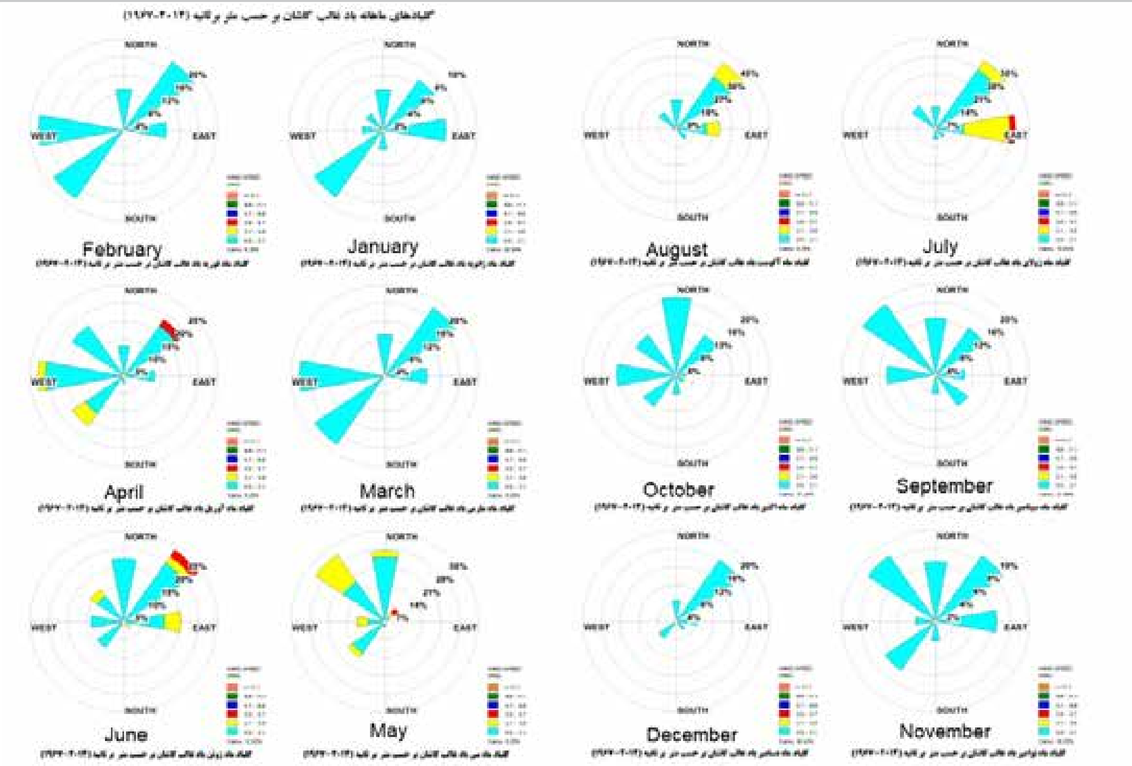
Wind Direction Information for Passive Architecture

If our objective is to just have natural ventilation throughout the year, we can rely on the yearly wind direction. [Fig-5] It is also important to note what the main and secondary directions are during the different seasonal winds; for example, in [Fig-6] [14], we can see the wind diagrams of four seasons in Kashan. Otherwise, if we want to utilize the wind in certain months [Fig-7] and time, the wind information generally is registered every three hours, i.e. 3:00 am, 6:00 am, 9:00 am, every day. If we want to use natural ventilation to create a natural cooling system, we need to know what the behavior of wind is like during hot months in different hours of the day. Particularly, it is helpful to know what the main direction of the wind is during the hottest time of day, during the warmest months of the year.

	A Scale for Rating Wind Strength, based on the Beaufort Scale				
Force	**Speed range (mph)**	**Effect on you**	**Effect on surroundings**	**Effect on lake surface**	**Effect on fresh snow**
0 – calm	Less than 1	None	Smoke rises straight up	Flat	None
1 – light air	1-3	None	Smoke drifts	Ripples	None
2 – light breeze	4-7	Felt on exposed skin	Leaves and grass rustle	Small wavelets, but none breaking	None
3 – gentle breeze	8-12	Hair ruffled, loose clothing flaps	Leaves and small twigs constantly moving	Larger wavelets; some breaking	A little drift near surface
4 – mod. breeze	13-18	Hair disarranged	Small branches move; loose dry grass picked up	Small waves form; some white horses	Large drifting
5 – fresh breeze	19-24	Walking inconvenienced	Small trees begin to sway	Many white horses; some spray	Widespread drifting
6 – strong breeze	25-31	Steady walking difficult	Large branches move	Crests form; more spray	Some blowing over head height
7 – near gale	32-38	Walking with great difficulty	Whole trees move	Moderate waves; much spray	Blowing in clouds above head height
8 – gale	39-46	Walking dangerous	Twigs breaking from trees	Foam in streaks along wind	Dense blowing clouds
9 – severe gale	47-54	Blown over, crawling difficult	Branches break; small trees blow over	Dense foam	
10 – storm	55-63	Progress impossible, even by crawling	Some trees uprooted; structural damage		
11 – violent storm	64-73		Many trees uprooted; widespread damage		
12 – hurricane	74 and above		Severe widespread damage		

Table illustrating the effect of wind speed on people and environment from Pedgely, Mountain Weather, taken from work done in Japan.

[Tab-3]



[Fig-7] Wind Directions Diagrams divided by Month of Kashan, from 1966 to 2005

3.5 Wind-Chill

“There is a lowering of body temperature due to the passing-flow of lower-temperature air. [Tab-4]
The effect of wind chill is to increase the rate of heat loss and reduce any warmer objects to the ambient temperature more quickly. Dry air cannot, however, reduce the temperature of these objects below the ambient temperature, no matter how great the wind velocity. For most biological organisms, the physiological response is to generate more heat in order to maintain a surface temperature in an acceptable range. The attempt to maintain a given surface temperature in an environment of faster heat loss results in both the perception of lower temperatures and an actual greater heat loss. In other words, the air 'feels' colder than it is because of the chilling effect of the wind on the skin. In extreme conditions, this will increase the risk of adverse effects such as frostbite.” [15]It is interesting to note that wind velocity depreciates from a high level to a lower level, and near the ground, it is almost zero. There are some other regional and local elements that have a powerful effect on wind direction and create a local breeze; like: seas or lakes, mountains and urban structures.

Cold and Fuzzy

The wind-chill factor describes how cold the air feels, but many factors influence that perception, including differences in wind exposure, sun, clothing and body type.

Temperatures feel colder when it's windy because the circulating air hastens the loss of body heat.

Temperature (°F)

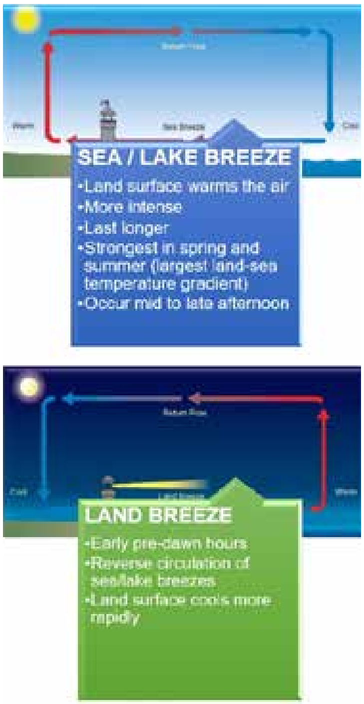
Frostbite Times: 5 mins. 10 mins. 30 mins.

Wind (mph) / Calm	-45	-40	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40
5	-63	-57	-52	-46	-40	-34	-28	-22	-16	-11	-5	1	7	13	19	25	31	36
10	-72	-66	-59	-53	-47	-41	-35	-28	-22	-16	-10	-4	3	9	15	21	27	34
15	-77	-71	-64	-58	-51	-45	-39	-32	-26	-19	-13	-7	0	6	13	19	25	32
20	-81	-74	-68	-61	-55	-48	-42	-35	-29	-22	-15	-9	-2	4	11	17	24	30
25	-84	-78	-71	-64	-58	-51	-44	-37	-31	-24	-17	-11	-4	3	9	16	23	29
30	-87	-80	-73	-67	-60	-53	-46	-39	-33	-26	-19	-12	-5	1	8	15	22	28
35	-89	-82	-76	-69	-62	-55	-48	-41	-34	-27	-21	-14	-7	0	7	14	21	28
40	-91	-84	-78	-71	-64	-57	-50	-43	-36	-29	-22	-15	-8	-1	6	13	20	27
45	-93	-86	-79	-72	-65	-58	-51	-44	-37	-30	-23	-16	-9	-2	5	12	19	26
50	-95	-88	-81	-74	-67	-60	-52	-45	-38	-31	-24	-17	-10	-3	4	12	19	26
55	-97	-89	-82	-75	-68	-61	-54	-46	-39	-32	-25	-18	-11	-3	4	11	18	25
60	-98	-91	-84	-76	-69	-62	-55	-48	-40	-33	-26	-19	-11	-4	3	10	17	25

Note: An updated wind-chill metric went into effect on Nov. 1, 2001.

[Tab-4] Wind-Chill Temperatures

3.6 Local and Regional Winds



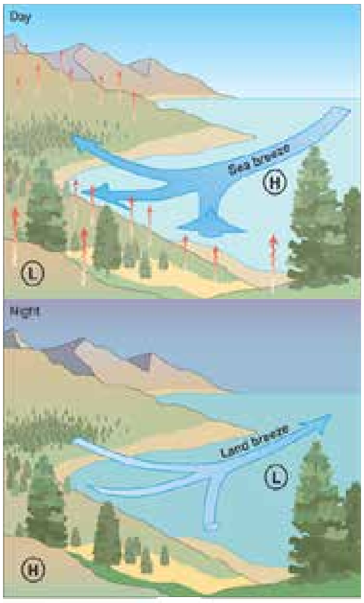
[Fig-8] Sea / Breeze vs Land Breeze

3.6.1 Sea / Lake – Land Breezes

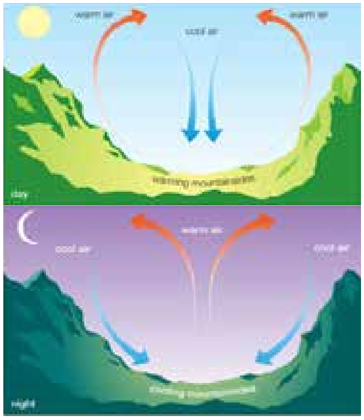
Bodies of water create significant winds. Sea-land breezes occur from uneven heating between the two areas. A body of water has a much higher heat capacity than land, which means it takes longer to either increase or decrease its temperature than land. During the day, the air over the land warms and then rises up, creating a low pressure. So the air over the sea flows into the land. This is analogous to the creation of geostrophic winds, where the land is the Equator and the sea is the northern hemisphere. At night, the water stays warm while the land cools off quickly, and the air reverses its flow, now seaward. [Fig-8] [16]

3.6.2 Valley / Mountain Breeze

"Bodies of water create significant winds. Sea-land breezes occur from uneven heating between the two areas. A body of water has a much higher heat capacity than land, which means it takes longer to either increase or decrease its temperature than land. During the day, the air over the land warms and then rises up, creating a low pressure. So the air over the sea flows into the land. This is analogous to the creation of geostrophic winds, where the land is the Equator and the sea is the northern hemisphere. At night, the water stays warm while the land cools off quickly, and the air reverses its flow, now seaward. [Fig-8] [16]
During the night, the land-sea breeze circulation occurs only near the coastline (within 100 km or so), and is very regular.
The contrast between the cool ocean air moving over the land and displacing the warm air often sets up a ***sea-breeze*** front. In humid locations (such as Florida), this often triggers afternoon thunderstorms. The land-sea breeze circulation doesn't have to occur by the ocean. Large lakes can also have these circulations. [17]
The strength of the breeze depends on the strength of the land-sea temperature difference (gradient). Sea/lake breezes occur mid to



[Fig-9] Sea Breeze



[Fig-10] Valley and Mountain Breeze

late afternoon when the land-sea temperature difference (gradient) is greatest and tends to be more intense than land breezes. Although, thunderstorms may develop if atmospheric instability is enhanced by surface heating.

A significant point to note is that the direction of the sea breeze is usually parallel with the coastline where there is a big mass like: a mountain or city effect on the wind direction. [Fig-9]

Another detail to consider is that we need to know the main atmospheric wind in the area as well as its direction. In this case, wind direction will be the total sum of the vector of different winds.

3.6.2 Valley / Mountain Breeze

"These breezes are similar to sea and land breezes. In the morning, the air on the mountain tops warms quicker than the air in the valleys. Warm air rises and the cooler valley air moves up the mountain slopes to form a valley breeze.

The process reverses in the evening, when the air on the mountain tops cools faster than that in the valleys. Warmer air in the valley rises, and the cooler air on the mountain tops moves downslope to take its place. This breeze is called a mountain breeze." [18]

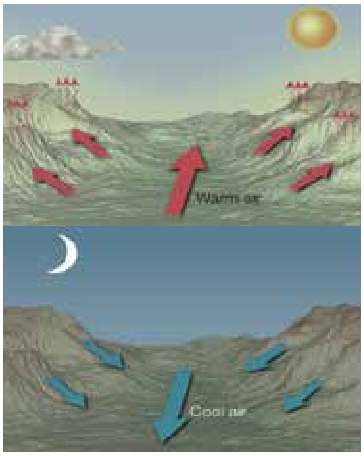
"In areas where there are mountains and valleys, we see a type of wind pattern known as mountain breezes and valley breezes. During the day, the surface of the mountain heats the air high up in the atmosphere, quicker than the valley floor can. As the warmer air expands, a low pressure is created near the top of the mountain. This attracts the air from the valley, creating a breeze that blows from the valley floor up towards the top of the mountain. Often birds known as raptors, such as eagles, hawks, condors and vultures, float on these breezes to preserve their energy. This wind pattern is known as a valley breeze.

In the evening, the mountain slopes cool the surrounding air more quickly than the air found lower in the atmosphere. This creates a high pressure, as air becomes more densely packed. The resulting high pressure causes winds to blow down the mountain towards the valley floor. This type of wind pattern is known as a mountain breeze.

Thus, in the daytime we typically see valley breezes as winds blow from the valley up towards the mountains. In the night, we often see mountain breezes as winds travel from the mountains down towards the valleys." [19] [Fig-10]

3.6.3 U Form Valley / Mountain Breeze

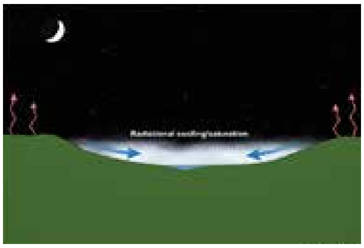
If the top view of the mountain forms the shape of a “U” more so than the normal flow between the top and bottom parts of the mountain, then there is another wind direction coming from the open part of the “U” shape to its closed part, during the day, and at night the wind direction is opposite, going from its closed part to its open part. [Fig-11]



[Fig-11] Wind Between the Mountains

3.6.4 Drainage Flow

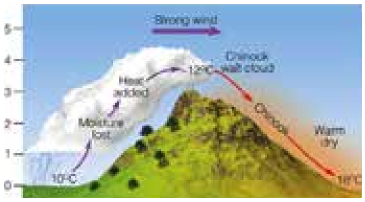
“Cold air is denser than warm air, and so cold air tends to collect in low-lying areas such as hollows or river bottoms, and this flow can generate light winds over terrain with little relief. Since the cold air collects in low lying regions, these regions are often the first to experience frost or radiation fog.” [20] [Fig-12]



[Fig-12] Radiation Fog; valley Fog

3.6.5 Chinook (or Foehn Winds)

These winds occur when air moves up over a mountain barrier and then down the leeward side. As the air descends it is adiabatically compressed and warmed. These relatively warm winds are also very dry. They usually occur over the east slope of the Rocky Mountains during the winter. Here they are called Chinook, which is the American Indian word for snoweater. A similar wind occurs in the Alps, where they are called Foehns. [Fig-13] [21]

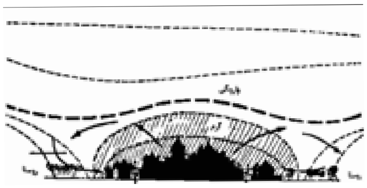


[Fig-13] Chinook- (Km: Altitude)

3.6.6 Suburb / City Breeze

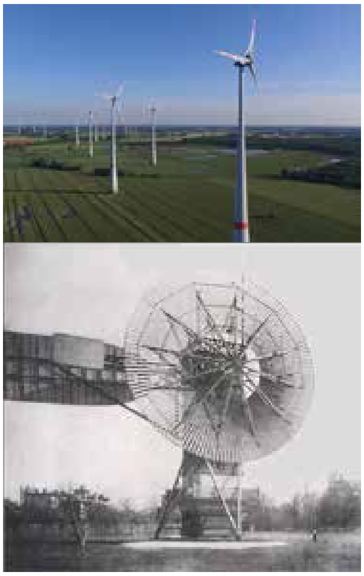
Though the name sounds pleasant, the country breeze is actually a result of the urban heat island, which sets up a circulation from the surrounding countryside into the city.

There is an air circulation that occurs between suburbs, when during the day, the density of buildings and apartments in the city absorb a lot of sun radiation and heat from cars and transport systems, making it warmer than in the suburbs. At night, the warm air on top of the city’s buildings goes up and cooler air from the suburbs, in the form of a breeze, moves into the city. [22] [Fig-14]



[Fig-14] City and Suburb Breeze

3.7 Wind Power



[Fig-15] Top: Wind Turbine Tower, Down: Charles Brush's Windmill in 1888

"According to Grogg, [23] *wind energy is one of the most cost effective of all the types of renewable energy. It does not create pollution or waste like fuel does, and it is not used faster than it is produced. However, to make wind a viable source of energy (electricity in particular), careful design of wind-capturing machines is necessary. Currently, wind energy is one of the least expensive of the alternative/renewable energy sources and is becoming more affordable as the technology improves and infrastructure develops. Wind energy comprises only a small amount of the total energy that reaches the earth. About 1.74 x 1017 Watts of power from the sun contact the earth each year. This is 160 times the total energy in the world's reserves of fossil fuels. Only a small portion, 1-2%, goes into the formation of wind (about 100 times the power that is stored in plants)."* [24]

"Alternative energy sources have become much more necessary as fossil fuels are depleted and pollute the environment." [25]

Wind-Tower (Electric-Turbine)

Wind turbines [Fig-15] movement provide a mechanical power that turn electric generators. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. [26] Net effects on the environment are far less problematic than those of non-renewable power sources.

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary surface with area A during the time t is: Where ρ is the density of air; v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); Avtρ is therefore the mass m passing through "A". Note that ½ ρv2 is the kinetic energy of the moving air per unit volume. $E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3,$

Power is energy per unit of time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine) is: [27] $P = \frac{E}{t} = \frac{1}{2}A\rho v^3$

Sheerwind

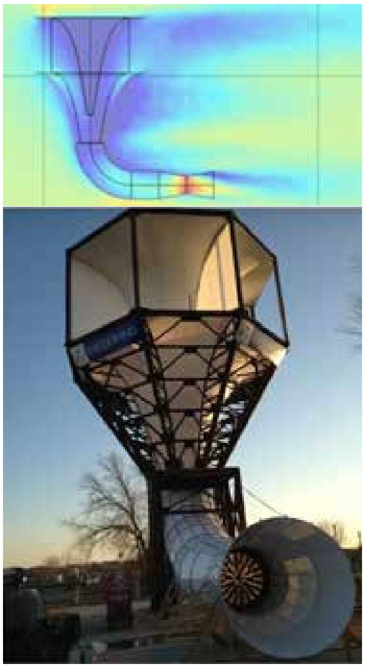
Wind turbine promises to produce six times the electrical power than traditional wind turbines.

This wind tower acts like a funnel, directing the wind from any angle, down through a tube to a ground based turbine generator. The funneling of the wind through a narrow passage effectively creates a *"jet effect"* increasing the velocity of the wind, while lowering the pressure. This is called the Venturi Effect. This speeds up the wind turbine mounted inside the narrowest portion and generates electricity. [Fig-16]

As such, it can capture and generate electricity at a much lower wind speed than current wind power technologies.

The idea is to produce so much more energy at a lower cost and more efficiently, that it might just be the answer to many problems of current wind turbine technology. Aside from the lower capital investment to get started, and increased efficiency and power generation, it also might be a solution to the ever growing problem of birds (and bats) being killed by traditional wind farms.

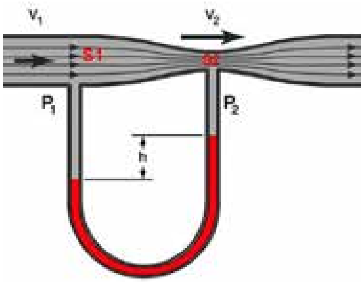
"This technology is not really new in the science of fluid dynamics; however, this is a new way to generate electricity, and if successful, promises to grow wind energy in a more eco-friendly way than ever thought possible." [28]



[Fig-16] Sheerwind Electricity Generator by Wind

3.8 Fluid physic theory and Wind

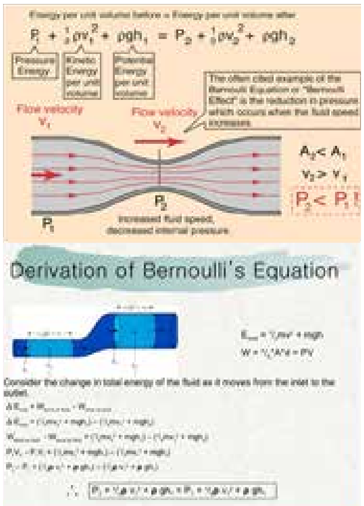
3.8.1 Venturi Effect



[Fig-17] Venturi-Meter Higher Velocity in 2 Point Push Up the Liquid in Tube P2 Because of Lower Pressure

"In fluid dynamics, an incompressible fluid's velocity must increase as it passes through a constriction in accord with the principle of mass continuity, while its dynamic pressure must decrease in accordance with the principle of conservation of mechanical energy. Thus, any gain in kinetic energy a fluid may accrue due to its increased velocity through a constriction, is balanced by a drop in pressure. [Fig-17] *By measuring the change in pressure, the flow rate can be determined, as in various flow measurement devices such as Venturi meters, Venturi nozzles and orifice plates.Referring to the adjacent diagram, using Bernoulli's equation in the special case of steady, incompressible, inviscid flows (such as the flow of water or other liquid, or low speed flow of gas) along a streamline, the theoretical pressure drop at the constriction is given by:"* [29]

3.8.2 Bernoulli's Principle / Bernoulli's Equation

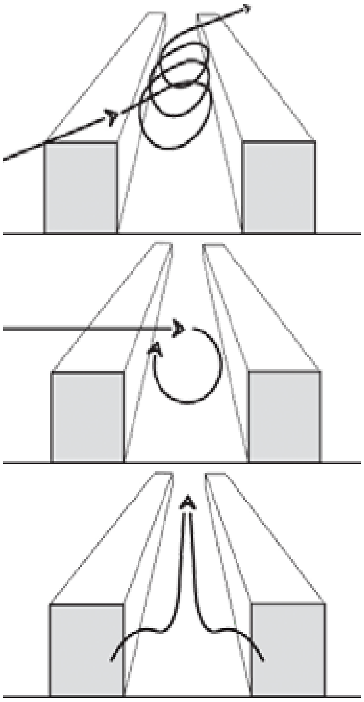


[Fig-18] Bernoulli's Equation

Essentially, Bernoulli equation comes from Venturi effect's statistics, and it features the equation of the fluid speed, the pressure in the two different sections in a tube, with diverse section dimensions. In fluid dynamics, Bernoulli's principle states that for an inviscid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. [30] [31] *"Bernoulli's principle* [Fig-18] *can be applied to various types of fluid flow, resulting in what is loosely denoted as Bernoulli's equation. In fact, there are different forms of the Bernoulli equation for different types of flow. The simple form of Bernoulli's principle is valid for incompressible flows (e.g. most liquid flows) and also for compressible flows (e.g. gases) moving at low Mach numbers. More advanced forms may in some cases be applied to compressible flows at higher Mach numbers (see the derivations of the Bernoulli equation)."* [32] Daniel Bernoulli published it in his book "Hydrodynamic" in 1738. [33]

3.9 Wind Flow Around Buildings

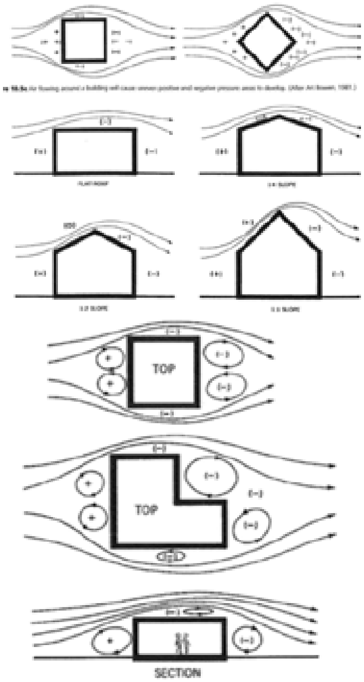
It is not possible to understand 100% of the behavior of wind between buildings during day and nighttime because wind does not always blow at the same time, in the same direction, at the same density, at the same height and same velocity. However, we can estimate wind behavior by its primary and secondary directions and its average velocity in these directions, and use aerodynamic rules to predict its behavior in its contact with buildings.



[Fig-19] Urban Winds in the Streets

3.9.1 Urban Wind Flow

“Three flow patterns can be distinguished in urban canyons [Fig-19] related to the wind direction at roof height: parallel, perpendicular or at an angle to the street axis. Wind speeds inside the street decrease from parallel to perpendicular approach flow. Therefore, the highest wind speeds can be expected to occur in southwest-northeast canyons in the Netherlands.
Flow patterns in the urban canyon, related to the wind direction at roof height; parallel, perpendicular or at an angle to the canyon axis. “The orientation of an outdoor space with regard to the wind direction highly influences the flow pattern occurring. At wind speeds higher than 1,5 m/s and a wind direction parallel or nearly parallel to the street axis (deviation of less than 30°) the wind can blow right through the canyon and there are almost no vortices. The streamwise velocity decreases along the canyon, as air escapes the canyon vertically at roof level. If the wind is more or less perpendicular to the canyon axis, three flow regimes can be distinguished: isolated roughness flow, wake interference flow and skimming flow, which are closely related to the height to width ratio of the canyon. All these flow regimes consist of a complex system of vortices, which rotate cross-canyon. Wind at oblique angles to the canyon axis will produce an along-canyon flow component added to the cross-canyon vortex structure, resulting in a cork screw-like airflow through the urban canyon. This flow pattern is basically a superposition of



[Fig-20]

the cross-canyon (perpendicular) and along-canyon (parallel) flow components.
In street grids, the streets (most) perpendicular to the wind direction may experience transverse flows at the downwind side of the street, as a result of the varying pressure in the street parallel to the wind direction. Alternating suction at the ends of the perpendicular streets can cause the airflow in the street to change direction 180°. Transverse flows are not present when the wind is oblique to the street grid, but corner streams forming at the street corners will flow along the windward façade of the street. Together with the (along-canyon component of) the corkscrew flow, this may cause discomfort." [34]

3.9.2 Wind Shade/Wind Tail

When wind finds an obstacle in its path, the wind-flow changes its direction. Wind-shade is the area that does not receive any direct wind. It depends on form, width, length, height and wind.

3.9.3 Aerodynamics of Wind Flow in the Architecture of Single Buildings

In order to get a deep understanding of the aerodynamics of wind in buildings, it is recommended to study all the relevant writings about this topic. A brief explanation of some of the most important ones will follow.A single building in an aerodynamic view point is a building that has a large amount of free land surrounding it.
It is divided into three types: [35]

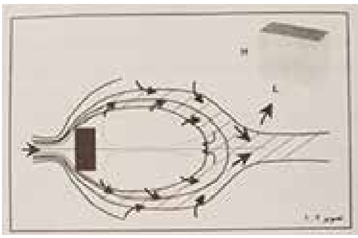
- Study on proportion and shape of the wind
- Study on proportion of wind shadow (tail)
- Study on the proportion of the building and velocity of wind in the aerodynamic area

3.9.3.1 Positive and Negative Pressure Points in Buildings

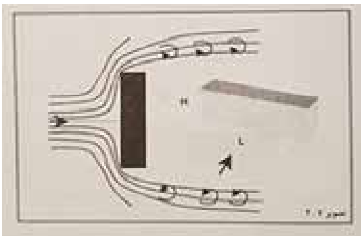
The surfaces of buildings that have direct contact with wind are the areas with positive pressure. Instead, where wind flows parallel or have no direct contact with building surfaces, there is a negative pressure. [Fig-20]

3.9.3.2 Building Proportions

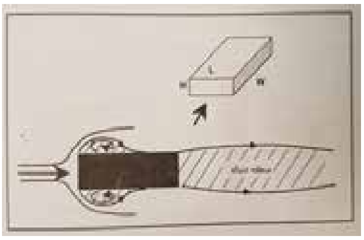
a. If we consider H: height of building, W: Wide and L: Length of building (Box)
If wind blows to building in H, L face and H = L > W then, line flow after a while creates an oval path and then joins together. [Fig-21]
b. If L > H > W the wind flow lines do not join together. They instead create a wind turbulence on two sides. [Fig-22]
c. If W / H > 1 and wind blows from H, L side, the length of wind-shade (wind-tail) is almost equal to W and there are also two little wind circles in the angle. [36] [Fig-23]



[Fig-21] Creation of Two Oval Wind Circles in the Back of the Building



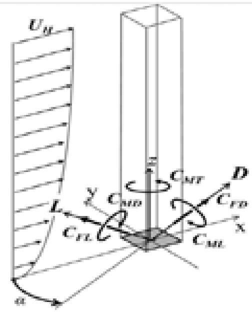
[Fig-22] Wind Turbulence on Two Sides



[Fig-23]

3.9.3.3 Aerodynamics of Tall Buildings

When super-tall buildings [Fig-24] are located among strong winds, the aerodynamic optimization of building shapes is considered to be the most efficient approach. Aerodynamic optimization is aimed at solving the problem from the source in contrast to structural optimization, which is aimed at increasing the structural resistance against winds. So it is necessary to use CFD; "The development of the Computational Fluid Dynamics method is a powerful tool for the prediction of wind environmental conditions around buildings. CFD techniques have been applied in predicting wind flow conditions around a multiple building configuration. Also presented is a limited model validation for those simulated configurations." (Elsevier Cince Ltd.)
From the result of the research of (CTBUH), [37] [Fig-25] tapered and setback models show better aerodynamic behavior.



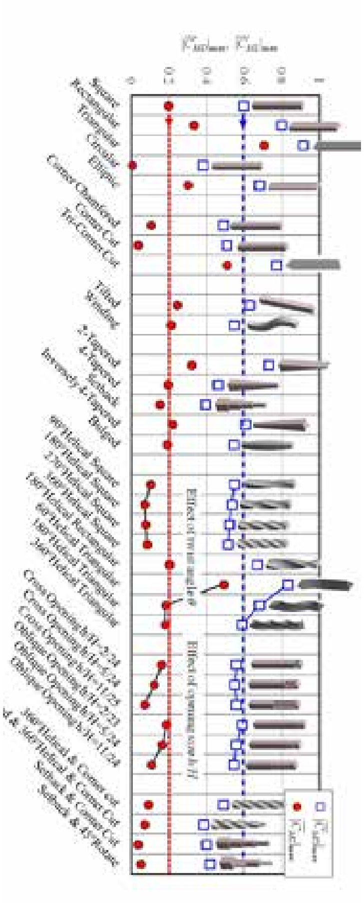
[Fig-24] Wind Power in Tall Buildings

3.9.3.4 Aerodynamics of Holes

Air movement over a hole depends on the hole dimension, wind speed and height of wind-flow.

- If wind flows with high speed on the same level of the ground inside of the hole, there is wind circle turbulence and low blending with surface air.

- If wind blows from a little higher level or with or a little lower velocity, wind circulates inside the hole, mixed a little with the air on top.



[Fig-25] Various Classifications of High Buildings aerodynamic and flow

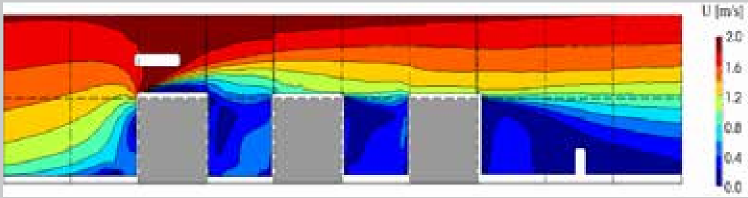
- If wind blows with very low velocity or in higher levels than before, wind circle turbulence will greatly decrease and mix more with the air flow on top of the hole. [Fig-26]
- If wind flows towards the blocks in a row; (L: distance between two blocks) L < H: height, then wind flow moves on top of the buildings and creates a low speed wind circulation of the air which is blocked between the blocks. The spaces between blocks are the safe places that do not receive high speed winds. [Fig-27 A,B]
- If L = or > 4H then if there is high speed wind, the space between the blocks is not as safe as before. [Fig-28]

- Sometimes block arrangements increase wind speed by the Venture effect or we can decrease wind speed by not having regular block arrangements. [Fig-29]

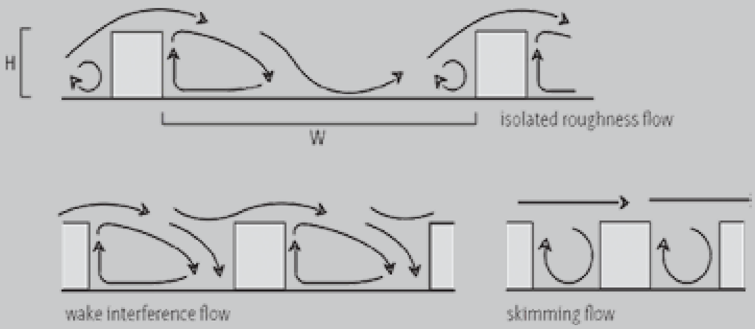
3.9.3.6 Aerodynamics of Openings

Wind movement inside buildings is dependent on the position, size and location of the opening and direction and speed of the wind. Different points around the building have different aerodynamic pressure. Wind enters where there is positive pressure, and exits wherever there is negative pressure.
"If we want to have natural ventilation inside a room, we need at least two windows; one should be wherever there is contact with positive pressure and another one should be where there is negative pressure, in order to create an expulsion effect. It is obvious that as the pressure is higher, the result is better. It is also best to have windows in two different sides and not in a row.
For normal natural ventilation, the wind should have a comfortable velocity." [Fig-30] [38]

If the wind enters from a little window and exits from a larger window, the air flow inside the room will increase by the Venture effect. [Fig-31] It also could direct wind from outdoors to indoors and then through the opening on (curve or V form) the roof, lead it out.
If the window divides the surface into two unequal parts, when the wind enters inside the room, it will have a little deviation to the side of the shorter surface side.



[Fig-27]B: Wind behavior CFD front of apartment blocks



Flow regime	H/W		Vortices characteristics
isolated roughness flow	< 0.1	< 0.2	2 co-rotative vortices
wake interference flow	0.1 – 0.7		
		0.2 – 1.6	1 main vortex
skimming flow	> 0.7	> 1.6	2 or more contra-rotative vortices

[Fig-28]

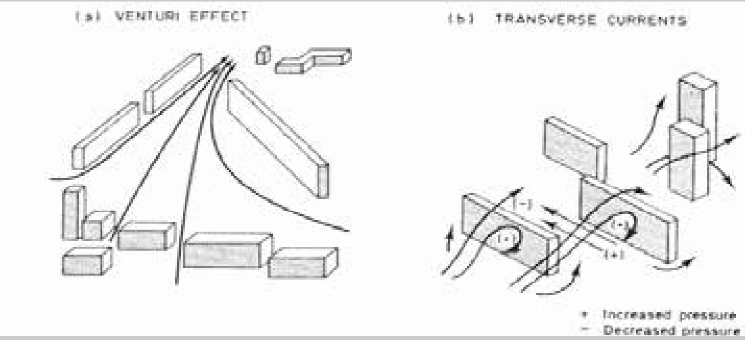
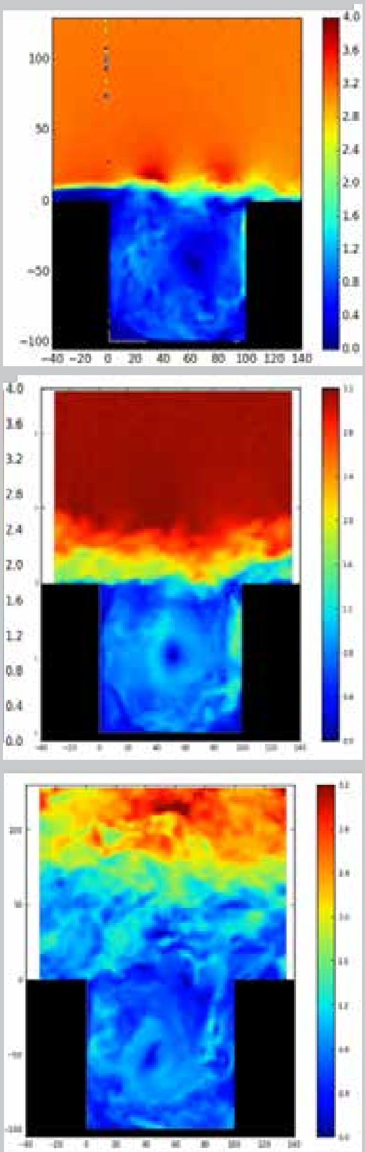
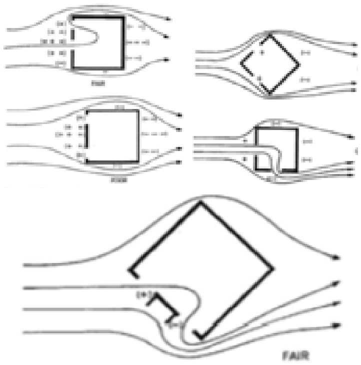


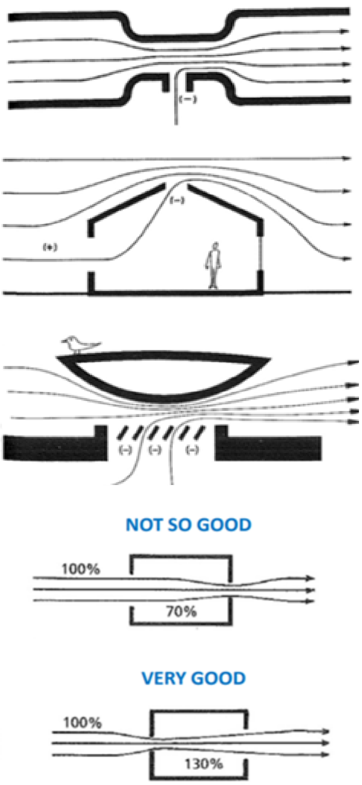
Fig-29]



[Fig-27]A- Wind behavior CFD in front of hole in different speed



[Fig-30]



[Fig-31] Interior Natural Wind Flow

3.9.4 Wind Tunnel Analysis

A wind tunnel is an instrument utilized for aerodynamic analyses to study the effects of air flowing inside or outside solid objects. A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means. The test object, often called a wind tunnel model, is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics. [39] [Fig-32]

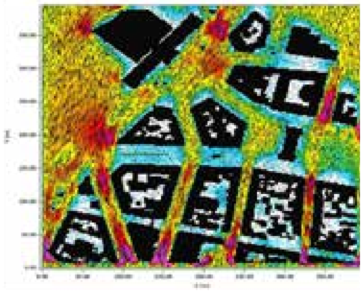
3.9.5 Computation Fluid Dynamics (CFD) by Software

"The developments of the Computational Fluid Dynamics (CFD) method is a powerful tool for the prediction of wind environmental conditions around buildings. CFD techniques have been applied in predicting wind flow conditions around a multiple building configuration. Also presented is a limited model validation for those simulated configurations". (Elsevier Cince Ltd.)
"The **ENVI_MET** *software is the world's only numerical climate model to analyze the interactions between urban development, architecture and landscape architecture as well as the microclimate and air quality down to a scale of one meter. It is thus, possible to investigate the interactions between climatological conditions and local environmental design."* [Fig-33] [40]
It is a powerful tool for designers to visualize moving air in a design project. Usually having a real analysis in a rail lab is very costly and takes a lot of time for modelling the project etc. **Flow Design (Autodesk)** is a perfect tool for architects and urban designers for understanding the impact in neighboring areas and provide more comfort and safety. [Fig-34] [41] Other products of Autodesk include Autodesk CFD [42] and Autodesk Revit (**Vasari**). Its wind tunnel tool, which simulates exterior airflow around your model, is an easy to use computational fluid dynamics (CFD) tool that is useful for early-stage conceptual analysis of airflow around building sites and building forms. For more info about the Wind Tunnel feature, see the Sustainability Workshop. For information about an updated version of this tool for Revit, check out Project Falcon for Revit.
There are many plug-ins that could add to the main Autodesk

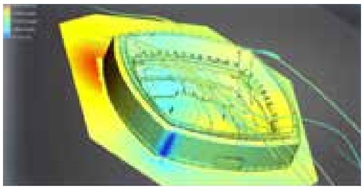
design programs and add CFD to programs. VirtualWind is a CFD plugin for Sketchup which was discontinued a while ago and this is easy to use too. [43] [Fig-35]

Fluent is one of the commercial software for computational fluid dynamics (CFD) widely used in many sectors of industry and academia, based on the finished volume method. [Fig-36]

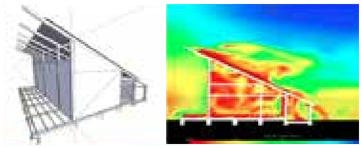
[Fig-32] Mclaren Wind Aerodynamic Test in Wind Tunnel



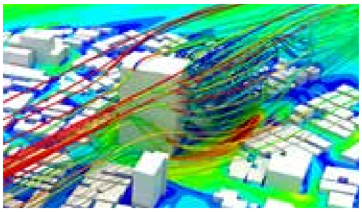
[Fig-33] Urban Wind Analysis by ENVI-MET



[Fig-33] Urban Wind Analysis by ENVI-MET



[Fig-35] Sketch Up CFD Analysis



[Fig-36] CFD by Fluent

3.10 Conclusion

Why is it necessary to use natural ventilation inside our buildings?

- 1. There is a limit on the gas and petroleum resources we could use to produce heat and cold inside the structures where we live. We then need new resources and methods in order to save these resources.
- 2. Using gas, petroleum, and nuclear power has produced very bad side-effects on our planet including: air and water pollution, global warming, the extinction of certain animal species, droughts, and various diseases.
- 3. It is critical that we find a secure and compatible way to live with nature that does not constrict our lifestyles and at the same time, can save our environment.

What are the reasons for air movement in a building?

- 1. The difference of density of air made by differences in temperature.
- 2. The difference of air or wind pressure between inside and outside or openings.

How should we study wind to best use it in architecture?

- 1. In order to use this important natural element, we need to know what are the primary and secondary powerful wind directions of the area, in the warmer months of the year.
- 2. What is the main-wind direction during the highest temperature hours of the day (from 1 PM to 4 PM)?
- 3. Is there any unsuitable wind that places and explores its direction and pinpoint when and where its period time is? In this way, we could avoid receiving this unsuitable wind and block its potential opening. We should check the metrological history of the area to see if there were any kinds of storms or hurricanes that took place in the area and control its microclimate.
- 4. Create an urban model of the neighborhood or area and analyze it by CFD software to explore wind circulation, positive or negative pressure, direction and its impact with surrounding

buildings. There are two strategies to analyze wind models. The first is wind tunnel and the use of a plastic model in a certain scale and smoke to see wind behavior in different directions and velocities. The second way is 3D modeling and the use of appropriate software, which is made to see the behavior of wind in contact with solid objects like: BIM, Revit, Autodesk structure analysis, CFD, Auto Desk Flow Design, Autodesk Vasari WA, FloVENT and many other software.

- 5. Conduct interviews with local people about the climate, temperature, wind intensity and directions in simple words.
- 6. Have enough knowledge of fluid-mechanic rules, fluid behaviors, and environmental findings. High positive pressure points and negative pressure points could be really helpful for the architect that wants to use passive natural ventilation in order to cool the inside and outside of buildings.

3.11 End Notes

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CHAPTER 4

Thermal Comfort and Passive Architecture Technology in Hot Temperature Areas

4.1 Objective

In the first part of this chapter, I will present the significance of thermal comfort. Then in the second part, I will explain what passive architecture is and what kind of strategies could be used for architecture projects. The main component of the second part comes from the research of B. Geetha and R. Velraj (from EEST Part A: Energy Science and Research, Vol. 29 (2012): 913–946) about passive architecture strategies. In the following chapters, we will see how traditional architecture can give passive answers to the hot climate problems we face. It will be necessary to have a real scale to measure our cases studies in order to see what kinds of passive strategies have been used.

4.2 Thermal Comfort

[Fig-1] The Ways Temperature Exchanges from Body to the Environment

The human body consists of chemical elements like oxygen, hydrogen, carbon, nitrogen etc.
Like any other chemical elements in the world, they can absorb or lose energy and heat. [Fig-1]

4.2.1 Definition

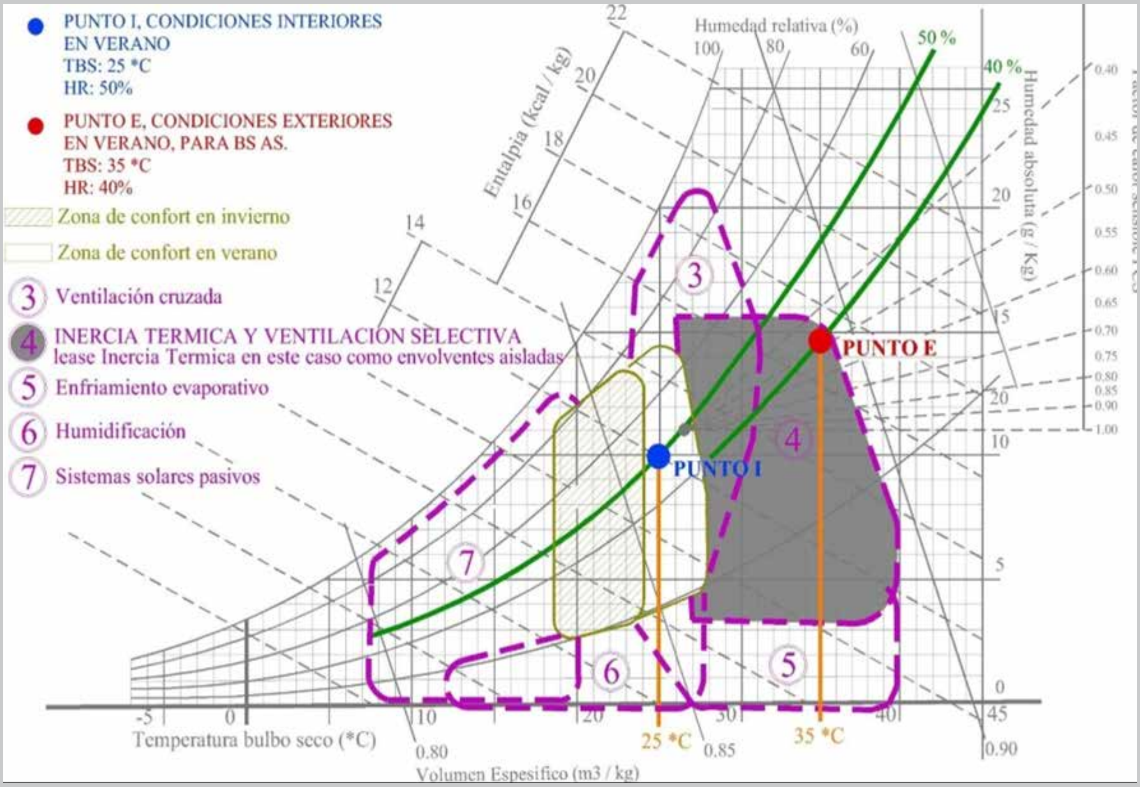
Air conditioning must provide the optimal conditions of well-being, so that the regulation mechanism of the human body dissipates the heat with minimum effort.
The feeling of comfort is related to local weather conditions. The basic parameters to control are:

- **Temperatures of air and surfaces** – This depends largely on the clothes people wear, the degree of physical activity and moisture content, and can be considered: **Winter: 18–23 ° C (22 ° C and 50% RH)** and **Summer: 23–27 ° C (25 ° C and 50% RH)**
  The temperature of the surfaces of the room surrounding the human body must be considered, since they affect the dissipation of its heat by its radiant heat. These surfaces must not exceed 5°C difference from the interior temperature.
- **Relative humidity** – A large part of the heat of the human body is dissipated by evaporation through the skin, favoring a relative humidity of low air throughout the year in **50%**. RH lower than 30% produces dry skin sensation, HR above 70% causes nausea due to the reduction of the ability to dissipate heat through sweating. **30% < HR < 70%.**

- **Movement of air** – This increases the proportion of moisture and heat dissipated, admitting a **speed** in zones of permanence of **6 to 8 m / min in winter and 8 to 12 m / min in summer**.

4.2.2 Design Condition

Humans should not take extreme conditions that cause oversizing. The feeling of comfort usually refers to statistical values of comfortable people in a range of 80 to 90%.
The external conditions to adopt are not the recorded maximums, since they usually appear in a few days and in a short lapse of time. The general criterion is to adopt an average at 3 pm in summer, which excludes extreme values. [1] [Fig-2]



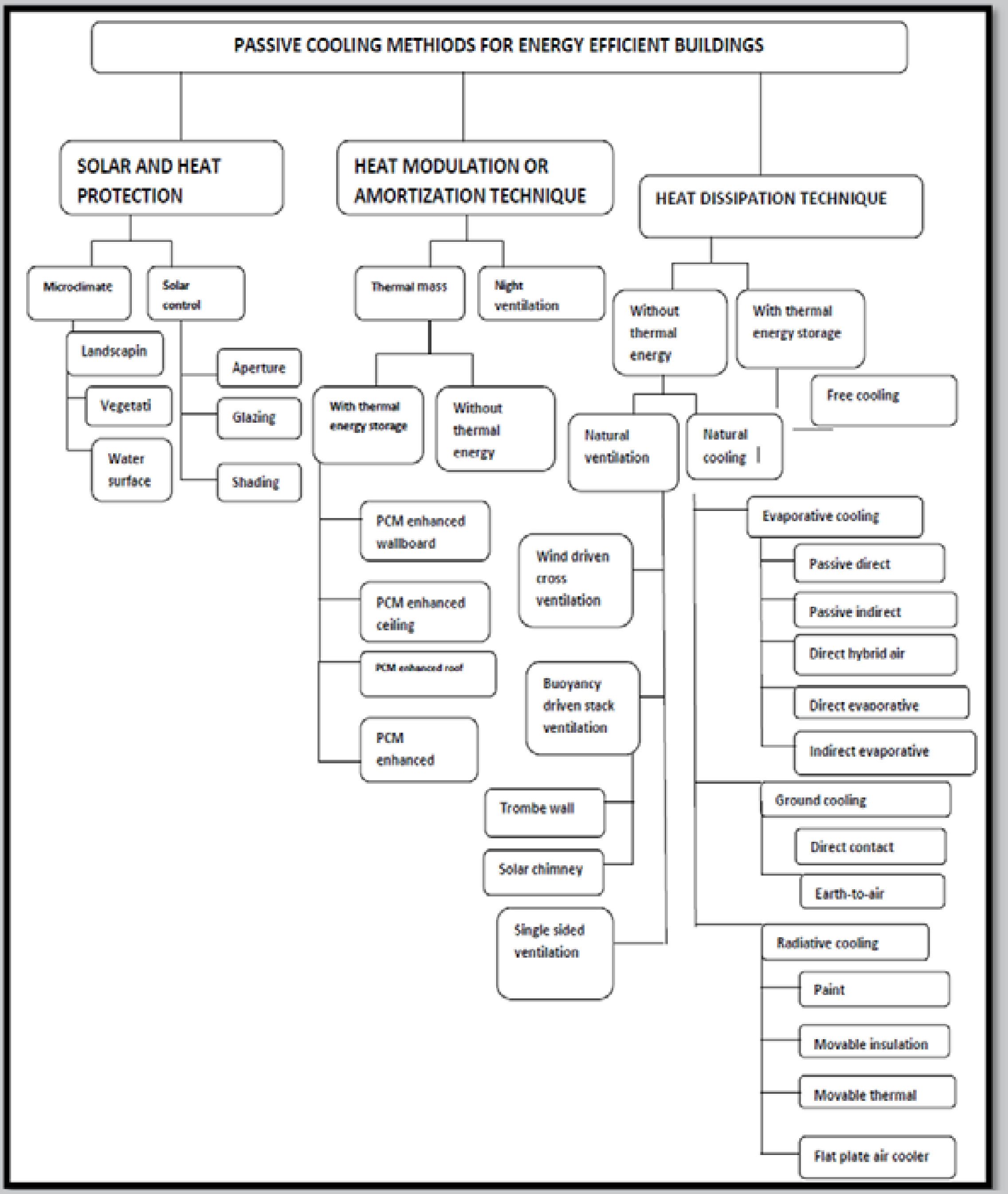
[Fig-2] Diagram of Temperature, Relative Humidity Comfort

4.3 Passive Cooling Techniques

"Cooling is the transfer of energy from a space or from the air, to a space, in order to achieve a lower temperature than that of the natural surroundings. In recent years, air conditioning systems are used to control the temperature, moisture content, circulation and purity of the air within a space, in order to achieve the desired effects for the occupants. The shortage of conventional energy sources and escalating energy costs has caused the re-examination of the general design practices and applications of air conditioning systems and the development of new technologies and processes for achieving comfort conditions in buildings by natural means. This topic – natural and passive cooling – covers all natural processes and techniques for cooling buildings. It is cooling without any form of energy input, other than renewable energy sources. Passive cooling techniques are also closely linked to the thermal comfort of the occupants." [2]
"*It is also possible to increase the effectiveness of passive cooling with mechanically assisted heat transfer techniques, which enhance the natural cooling processes."* [3]
"The passive cooling of buildings is broadly categorized under three sections."

- (i). Heat prevention/reduction (Reduce heat gains)
- (ii). Thermal moderation (Modify heat gains)
- (iii). Heat dissipation (Remove internal heat)

The various methods adopted for each of these, are further classified and given in the following diagram. [Fig-3] [4]



[Fig-3] Classification of Passive Cooling Methods in Energy Efficient Buildings by N. B. Geetha, R. Velraj

4.3.1 Heat Prevention / Reduction (Reduce Heat Gains)

4.3.1.1 Microclimate

"Climate is the average of the atmospheric conditions over an extended time over a large region. Small-scale patterns of climate, resulting from the influence of topography, soil structure, ground and urban forms, are known as microclimates. The principal parameters characterizing climate are air temperature, humidity, precipitation and wind.
The climate of cities differs from the climate of the surrounding rural areas, due mainly to the structure of cities and the heat released by vehicles. In general, the climate in cities is characterized by ambient temperatures, reduced relative humidity and reduced received direct solar radiation." [5]
"The microclimate of an urban area can be modified by appropriate landscaping techniques, with the use of vegetation and water surfaces, and can be applied to public places, such as parks, playgrounds and streets." [6]
"The first stage in managing higher future internal temperatures in buildings is to attempt to make the external air as cool as possible. Within the built environment, this involves enhancing the green and blue infrastructure of parks, trees, open spaces, open water and water features. There is a growing interest in the use of rooftop gardens, green walls and green roofs for their cooling effect." [7]
Parks and other open green spaces can be beneficial through their cooling effects in summer, through shading and transpiration,"
[8–10] and improved access for natural wind-driven ventilation. In addition, the presence of water, plants and trees contributes to microclimate cooling, and is an important source of moisture within the mostly arid urban environment [11]. Urban surfaces should be cool or reflective to limit solar gain. Pavements, car parks and roads can be constructed with lighter finishes and have more porous structures.
Limor Shashua-Bar et al. [12] studied the climatic analysis of landscape strategies for outdoor cooling in a hot-arid region, considering the efficiency of water use. Six landscape strategies were studied, using different combinations of trees, lawn, and an overhead shade mesh.

4.3.1.1.1 Vegetation

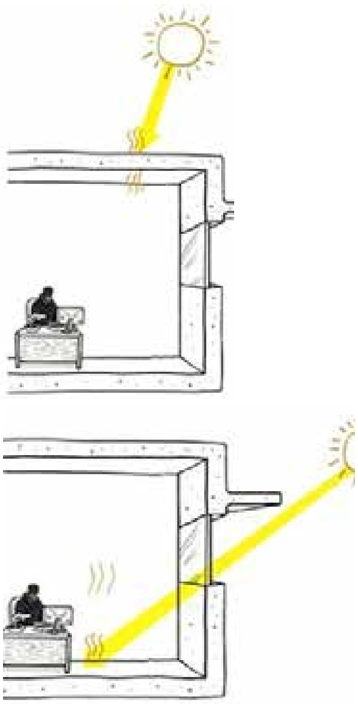
Vegetation moderates the microclimate by lowering the air and surface temperatures and increasing the relative humidity of the air. Likewise, plants can help with the air pollution problem. It could filter the dust and decrease the level noise source problems.
Trees are one important element that can change the urban micro-climate. While as a bioclimatic responsive design element, it produces shade, its main disadvantage is blocking the wind. [13] In addition, the effects of specific urban tree types, for example, the different leaf area densities and evapotranspiration rates of urban trees, influence solar access and heat exchanges if planted around buildings. [14]
In different studies, results that influence the orientation and proportion of plant-covered wall sections on the thermal behavior of typical buildings during the summer is very important. [15] We can see in all the studied cases that the thermal effect of trees was found to depend mainly on its canopy coverage level and planting density on the urban street, and little on other species characteristics.

Vegetation

4.3.1.1.2 Water Surfaces

Water surfaces modify the microclimate of the surrounding area, reducing the ambient air temperature, either by evaporation, or by the contact of the hot air with the cooler water surface. Fountains, ponds, streams, waterfalls or mist sprays may be used as cooling sources, for lowering the temperature of the outdoor air and of the air entering the building.
The asphalt and concrete used in urban environments is typically too dense to allow water permeability, and therefore, drastically limits the latent heat exchange. The water and air passage allows latent heat exchange, and therefore decreases the temperature of the pavement. This, in turn, assists trees and other landscape root systems to better access air and nutrients, providing cooler root zones, which result in larger and denser shading landscape materials. [16] [Fig-4]

[Fig-4] Cooling Public Spaces Using Fountains



[Fig-5] Control Sun Rays Entrance from the Window to Have Best Action in Summer and Winter

4.3.1.2 Solar Control

"Solar radiation reaches the external surfaces of a building in direct, diffuse and reflected forms and penetrates to the interior through transparent elements. In general, incident radiation varies with geographic latitude, the altitude above sea level, the general atmospheric conditions, the day of the year, and the time of day. For a given surface, incident radiation varies with the orientation and the surface's angle to the horizontal plane." [17]

The solar radiation into an interior space causes high indoor temperature problems. Thus, it is of vital importance that solar radiation is controlled. Solar control denotes the complete or partial, permanent or temporary exclusion of solar radiation from building surfaces or the interior or surrounding spaces. Solar control may be achieved through the following techniques.

4.3.1.2.1 Aperture

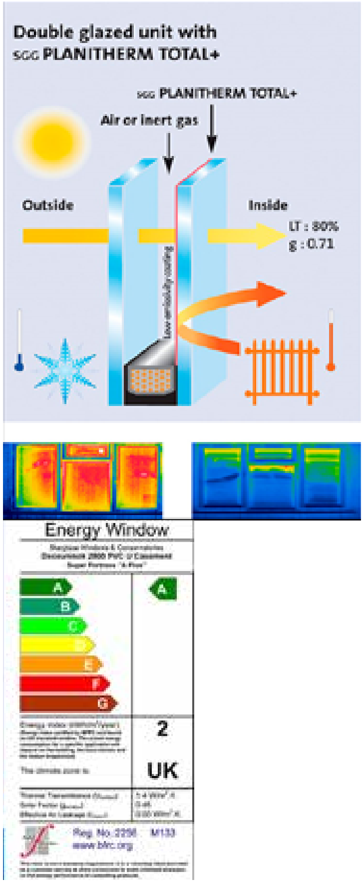
"The appropriate combination of the orientation, size and tilt of the various openings on the building's envelope is of vital importance. This is because these parameters affect the surfaces' view of the sun and sky over the daily and monthly cycles. [18] *Mazria* [19] *defines the best orientation for the solar apertures of a building as one which receives the maximum amount of solar radiation in winter and the minimum amount in summer.* [Fig-5] *Designing the building form from the perspective of energy efficiency means considering the floor area, perimeter, building height and aspect ratio. A study, gave out an aspect ratio of 1:1.25 for Ankara* [20] *and this value is accepted for buildings with a 100 m² floor area."* [21]

4.3.1.2.2 Glazing

"The thermal properties of the glazed surfaces of a building affect the penetration of solar radiation to the interior. The influences of channel width and the dimensions of the inlet and outlet openings affect the convection process, and hence, affect the overall heating performance. Using double glazing could increase the flow rate by 11 – 17%. On the other hand, insulating the interior surface of the storage wall for summer cooling can avoid excessive overheating due to south facing glazing." [22]

“Transparent selective films represent an interesting option for the control of solar heat gain, to be used to treat windows or façades, especially in existing buildings, to improve the performance of windows and transparent façades. Transparent selective coatings and films are being manufactured nowadays by all major glass and glazing companies all over the world. They represent quite an advanced technology and are being increasingly used in double and even triple glazing systems to improve window performance.” [23] [Fig-6]

In a recent study, Bakker and Visser [24] demonstrated that a larger use of solar control glazing in residential buildings in European Union countries could avoid the emission of up to 80 million tons of CO2, which represents 25% of the target established by the European Commission for energy savings in the residential sector in 2020. [25]



[Fig-6] Window Glazing

4.3.1.2.3 Shading

Shading denotes the partial or complete obstruction of the sunbeam directed toward a surface by an intervening object or surface. The shadow varies in position and size depending upon the geometric relationship between the sun and the surface concerned. [26]

Shading devices are essentially a second link between daylighting and the thermal performance of perimeter spaces. Thus, an integrated analysis should be carried out in order to take into account the interactions between the different parameters and to attain optimal results. However, with a few exceptions, an integrated façade analysis is not applied at the early design stage, when critical decisions with a small economic impact, could lead to significant energy savings during the lifetime of the building, and a simultaneous improvement in interior conditions. [27] [Fig-7]

Fig-7] GAMMASTONE AIR | Solar Shading from www.archiproducts.com

4.3.2 Thermal Moderation (Modify Heat Gains) Shifting of Day Heat to Night for Removal

Heat modulation or amortization techniques are one of the best ways to control heat in buildings. The thermal mass of a building can be achieved either by the use of bulky construction material or by the use of additional energy intensive phase change materials in the building system.

4.3.2.1 Thermal Mass in Construction Material

"In the first method, the thermal mass of a building (typically contained in walls, floors, partitions – constructed of materials with high heat capacity) absorbs heat during the day and regulates the magnitude of indoor temperature swings, reduces peak cooling load and transfers a part of the absorbed heat to the ambient in the night hours. The remaining cooling load can then be covered by passive cooling techniques." [28]

- a. Thermal Mass with Thermal Energy Storage
- b. Thermal Mass without Thermal Energy

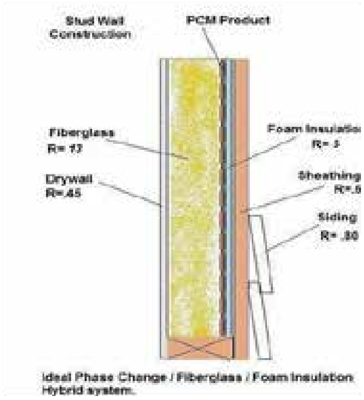
"The structural mass within the existing commercial buildings can be effectively used to reduce operating costs through simple adjustments of zone temperature set points within a range that does not compromise thermal comfort. The cooled mass and higher on-peak zone set point temperatures lead to reducing on-peak cooling loads for the HVAC equipment, which results in lower peak energy and demand charges. The potential for using building thermal mass for load shifting and peak demand reduction has been demonstrated in a number of simulation, laboratory and field studies. [29-37] This strategy appears to have significant potential for demand reduction if applied within an overall demand response program; because the added demand reduction from different buildings can be large. The experiments showed the reduction in the peak cooling load to be as much as 40%. Keeney and Braun [35] developed a building cooling control strategy and conducted an experiment in a large office building. They found that the pre-cooling strategy could limit the peak cooling load to 75% of the cooling capacity." [38]

4.3.2.2 Thermal Mass Using PCM Based Systems

"In order to enhance the thermal storage effect of the building fabric, thermal mass with high thermal inertia, such as phase change materials (PCMs), is advised to be used. The PCM can be integrated into the building fabric to enhance the thermal storage effect and improve the thermal comfort for the inhabitants. Generally speaking, the PCM can be integrated with almost all types and components of building envelopes, but different application areas have their own unique configurations and characteristics. Pasupathy et al. [39] presented a detailed review on the PCMs' incorporation in buildings, and the various methods used to contain them for thermal management in residential and commercial establishments. Among all the PCM applications for high performance buildings, the PCM integration in wallboards, roof and ceiling, and windows is most commonly studied, due to its relatively more effective heat exchange area and more convenient implementation." [40]

4.3.2.2.1 PCM in Wallboards

"Generally, there are two ways to integrate phase change materials with building walls: "attachment" and "immersion." "Attachment" is to attach one or several PCM integrated wallboard layers to the wall. In this case, the PCM does not constitute the material of the wall, but is integrated with the attached layers beyond the wall. As the PCM is only integrated with the wallboard instead of the main wall, it can be considered as part of the indoor decoration work after the construction of the building envelopes. The separate PCM layer, such as PCM integrated gypsum board and PCM integrated composite panel, allows a separate mass production of certain wallboards by typical companies; thus, it increases the efficiency and reduces the overall cost. Many early studies focused on the PCM playing a role as a better thermal storage mass than the traditional masonry wall in the application of collector-storage building wall ("Trombe Wall")." [41] [Fig-8]



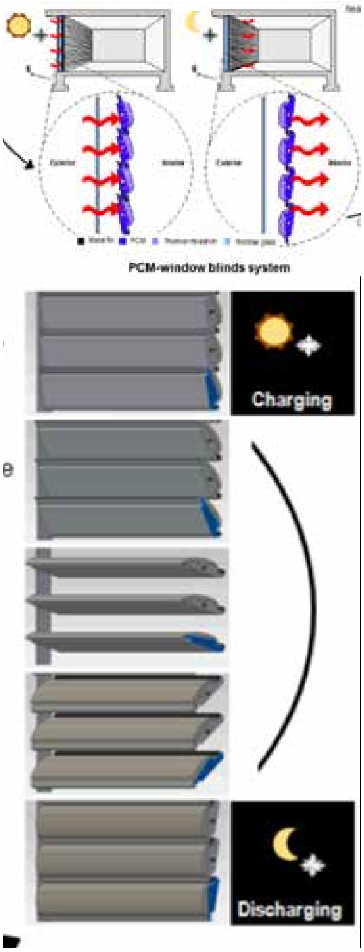
[Fig-8] (http://pcmsouth.com) PCM

4.3.2.2.2 PCM in Roof and Ceiling

"The PCM assisted ceiling system is more utilized in building applications due to its easier installation and implementation with the envelope. In order to achieve thermal storage capacity approximately equal to the heat gains within the space during the daily cycle and to incorporate this system in a light weight and retrofitted building, a new concept of a ceiling panel was developed by Koschenz and Lehmann; [42] *their ceiling panel is made of a mixture of a micro-encapsulated PCM and gypsum. Furthermore, capillary tubes and aluminum fins are incorporated into the thermal mass to enhance the heat transfer processes. During daytime occupancy, the PCM ceiling panel is directly exposed to the indoor heat sources and functions as a heat sink, while during the nighttime, the absorbed heat can be released by the circulation of cold water in the capillary tubes or by the night air ventilation."* [43] [Fig-9]

[Fig-9] PMC on Roof

4.3.2.2.3 PCM in Glass Windows



[Fig-10] PMC Window Blinds System

"From the above descriptions of the PCM applications, it is seen that most of the studies and applications have focused on the "opaque" part of the building envelopes, such as walls, ceilings, and floors. However, it is noticed that the "transparent" part of the building envelopes, i.e., the window, has a much lower thermal resistance than other parts of the envelopes. Very few researchers have investigated "PCM filled glass windows" due to the characteristics of the PCM and its relatively difficult implementation. Ismail and his coworkers did a series of theoretical and experimental studies on composite and PCM glass systems. [44-45] [Fig-10] *Santamouris and Wouters* [46] *said that night ventilation is suitable for areas with a high daily air temperature range, and where nighttime air temperature is not so cold as to create discomfort. However, since the required daily air temperature range would depend on other parameters, such as the air exchange rate and thermal storage capacity of the building, it may be difficult to set the optimum value for the daily air temperature range alone. In fact, the proposed daily air temperature range for achieving enough cooling effect of night ventilation varies among researchers."* [47]

4.3.2.3 Use of Night Coolness for Day Cooling

In the second method, the unoccupied building is pre-cooled during the night by night ventilation, and this stored coolness is transferred into the early morning hours of the following day, thus reducing energy consumption for cooling by close to 20%. [48]
"Night ventilation techniques are based on the use of the cool ambient air to decrease the indoor air temperature as well as the temperature of the building's structure. The cooling efficiency of night ventilation is based mainly on the relative difference between indoor and outdoor temperatures during the night, the air flow rate, the thermal capacity of the building, and the efficient coupling of the air flow and thermal

mass.
In recent studies, night ventilation techniques have been applied successfully to many passively cooled or low-energy buildings, particularly in European countries. Several studies reported the results of the monitoring of passive cooling performances applied in different types of buildings." [49-51]

4.3.3 Heat Prevention / Reduction (Reduce Heat Gains)

"In many cases, the avoidance and modulation of heat gains cannot maintain indoor temperatures at a control level. A more advanced cooling strategy includes heat rejection to heat sinks, such as the upper atmosphere and the ambient sky, by the natural processes of heat transfer. The design of a building is a very important factor which influences the cooling potential of a natural cooling technique. Natural cooling refers to the use of natural heat sinks for excess heat dissipation from interior spaces, including: natural ventilation, evaporative cooling, ground cooling and radiative cooling, and also the use of a PCM based system for free cooling." [52]

4.3.3.1 Without Thermal Energy

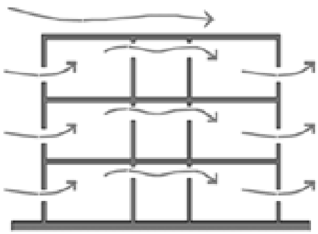
"Natural ventilation is the most important passive cooling technique. In general, the ventilation of indoor environments is also necessary to maintain the required levels of oxygen and air quality in a space. Traditionally, ventilation requirements were achieved by natural means. In the majority of older buildings, infiltration levels were such as to provide considerable amounts of outdoor air, while additional requirements were satisfied by simply opening the windows.
Modern architecture and the energy-conscious design of buildings have reduced air infiltration to a minimum, in an attempt to reduce its impact on the cooling or heating load. Better construction has resulted in buildings being sealed from the outdoor environment. In particular, the construction of large glass office-buildings, which do

not allow the opening of windows, has further eliminated the possibility of using natural ventilation for supplying fresh air to indoor spaces. The successful design of a naturally ventilated building requires a good understanding of the air flow patterns around it and the effect of the neighboring buildings. The objective is to ventilate the largest possible part of the indoor space. The fulfillment of this objective depends on the window location, interior design and wind characteristics." [52]

Classification of Natural Ventilation

- Wind driven cross ventilation
- Buoyancy driven stack ventilation: a. Trombe wall, b. Solar chimney
- Single sided ventilation

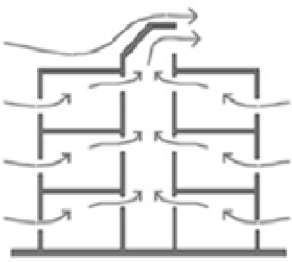
4.3.3.1.1 Wind-Driven Cross Ventilation



[Fig-11] Concept of Wind-Driven Cross Ventilation System

"Wind-driven cross ventilation occurs via ventilation openings on opposite sides of an enclosed space. [Fig-11] *shows a schematic of cross ventilation serving a multi-room building. The building floors pan depth in the direction of the ventilation flow must be limited to effectively remove the heat and pollutants from the space by typical driving forces. A significant difference in wind pressure between the inlet and outlet openings and a minimal internal resistance to flow are needed to ensure sufficient ventilation flow."* [53]

4.3.3.1.2 Buoyancy-Driven Stack Ventilation

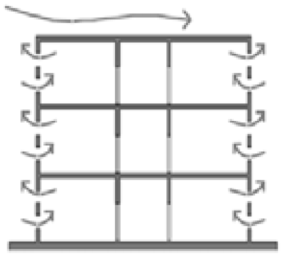


[Fig-12] Concept of Buoyancy Driven Stack Ventilation System

"Buoyancy-driven stack ventilation or displacement ventilation (DV) relies on density differences to draw cool, outdoor air in at low ventilation openings and exhausts. [Fig-12] *shows the schematic of stack ventilation for a multi-storied building. A chimney or atrium is frequently used to generate sufficient buoyancy forces to achieve the needed flow. However, even the smallest wind will induce pressure distributions on the building envelope that will also act to drive the airflow."* [54]

4.3.3.1.3 Single-Sided Ventilation

“Single-sided ventilation typically serves single rooms, and thus, provides a local ventilation solution. [Fig-13] *shows a schematic of single-sided ventilation in a multi-room building. The ventilation airflow in this case, is driven by room-scale buoyancy effects, small differences in envelope wind pressures. Consequently, the driving forces for single-sided ventilation tend to be relatively small and highly variable”.* [55]

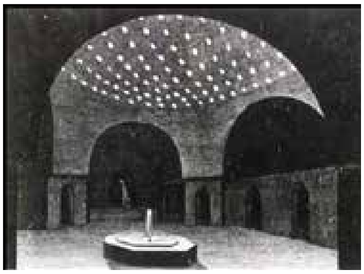


[Fig-13] Concept of Single-Sided Ventilation System

4.3.4 Natural Cooling

4.3.4.1 Evaporative Cooling

“Evaporative cooling is a process that uses the effect of evaporation as a natural heat sink. Sensible heat from the air is absorbed to be used as latent heat necessary to evaporate water. The amount of sensible heat absorbed depends on the amount of water that can be evaporated. Evaporative cooling is a very old process, having its origin some thousand years ago, in ancient Egypt and Persia. [Fig-14] *Modern evaporative coolers are based on the prototypes built in the early 1900s in the United States. Amer* [56] *has found that among some passive cooling systems, evaporative cooling gave the best cooling effect, followed by the solar chimney, which reduced inside air temperature by 9.6°C and 8.5°C, respectively.*

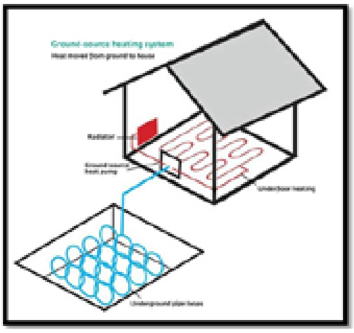


[Fig-14] Evaporation Passive Cooling System in Middle East

Passive direct systems include the use of vegetation for evaporation, the use of fountains, sprays, pools and ponds as well as the use of porous material saturated with water. Trees and other plants transpire moisture in order to reject their sensible heat. The theoretical analysis of the role of plant evapotranspiration has shown, that the evapotranspiration from one tree can save 250 to 650 kWh of electricity used for air-conditioning per year.” [57]
One acre of grass can transfer more than 50 GJ on a sunny day, while evapotranspiration from wet grass can reduce the ground surface temperature by 6-8°C below the average surface temperature of the bare soil. Various types of heat exchangers, which consume only the fan and water pumping power, were studied theoretically and experimentally by various researchers for indirect evaporative cooling applications. These studies are summarized as follows. Ren and Yang [58] *developed an analytical model for the coupled heat and mass transfer*

processes under real operating conditions, with parallel counter-flow configurations. They considered the effects of spray water evaporation, spray water temperature variation and spray water enthalpy change along the heat exchanger surface in the model. El-Dessouky et al., [59] *and Heidarinejad and Bozorgmehr carried out experimental studies on indirect evaporative cooling, and examined two-stage indirect/direct evaporative cooling."* [60-61]

4.3.4.2 Ground Cooling



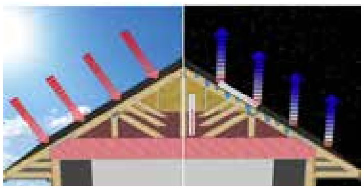
[Fig-15] Geo Thermal System

"The concept of ground cooling is based on heat dissipation from a building to the ground, which during the cooling season has a temperature lower than the outdoor air. [Fig-15] *This dissipation can be achieved either by direct contact of a significant section of the building envelope with the ground, or by injecting air that has been previously circulated underground into the building by means of earth-to-air heat exchangers. A building exchanges heat with the environment by conduction, convection and radiation. For an ordinary building, the main mechanism is convection, since most of the building envelope is in contact with ambient air. Then comes radiation and finally conduction, since the area of the building envelope in contact with the ground is the smallest. The principle of ground cooling by direct contact is to increase conductive heat exchange. The building temperature drops, because the ground is at a lower temperature than the air during the cooling period.*

Carnody et al. [62] *has explained that earth-contact buildings have advantages related not only to their energy performance, but also to visual impact aesthetics, preservation of surface open spaces, environmental benefits, and noise-vibration control and protection."* [63]

4.3.4.3 Radiative Cooling

"Radiative cooling is based on heat loss by long wave radiation emission from one body towards another body of lower temperature, which plays the role of the heat sink. In the case of buildings, the cooled body is the building and the heat sink is the sky, since the sky temperature is lower than the temperatures of most of the objects on Earth. [Fig-16] *This is the mechanism that allows the Earth to dissipate the heat received from the sun, so as to maintain its thermal equilibrium. There are two methods of applying radiative cooling in buildings: direct, or passive radiative cooling, and hybrid radiative cooling. In the first, the building envelope radiates towards the sky and gets cooler, producing heat loss from the interior of the building. In the second case, the radiator is not the building envelope, but usually a metal plate. The operation of such a radiator is the opposite of an air flat-plate solar collector. Air is cooled by circulating it under the metal plate, before it is injected into the building. The various concepts of radiative cooling of buildings are explained below.*



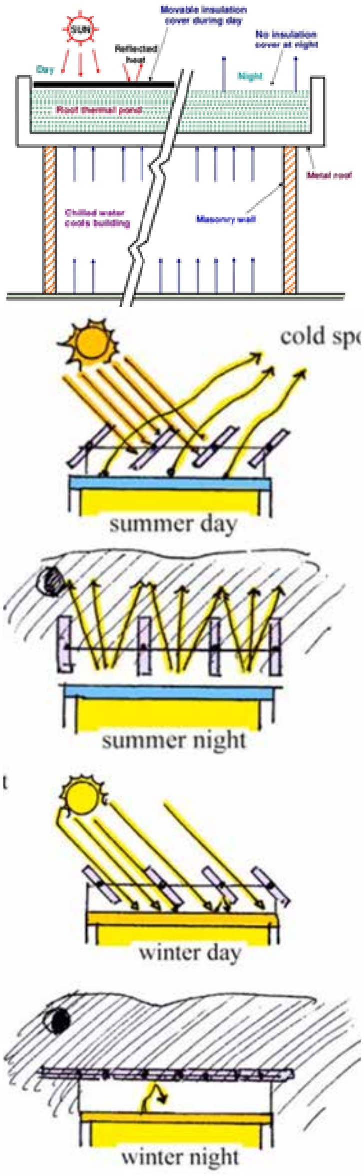
[Fig-16] Radiative Cooling from the Rooftop to Sky at Night

4.3.4.3.1 Paint

The simplest passive radiative cooling technique is to paint the roof white. White paint does not significantly affect the radiation rate at night, since both white and black paints have almost the same emissivity in the long wave range. The advantage of a white painted roof is that by absorbing less solar radiation during the day time, the temperature of the roof remains lower, and can therefore be easily cooled by radiation at night.

4.3.4.3.2 Movable Insulation

Movable insulation systems are applied on the roof of buildings. They consist of an insulating material that can be moved over the roof of the building. These systems allow the exposure of the thermal mass of the roof to the sky during the night. During the day, the mass is covered by an insulating layer to minimize the heat gain in the thermal mass due to solar radiation. [Fig-17]



[Fig-17] Roof Movable Insulation and Thermal Mass

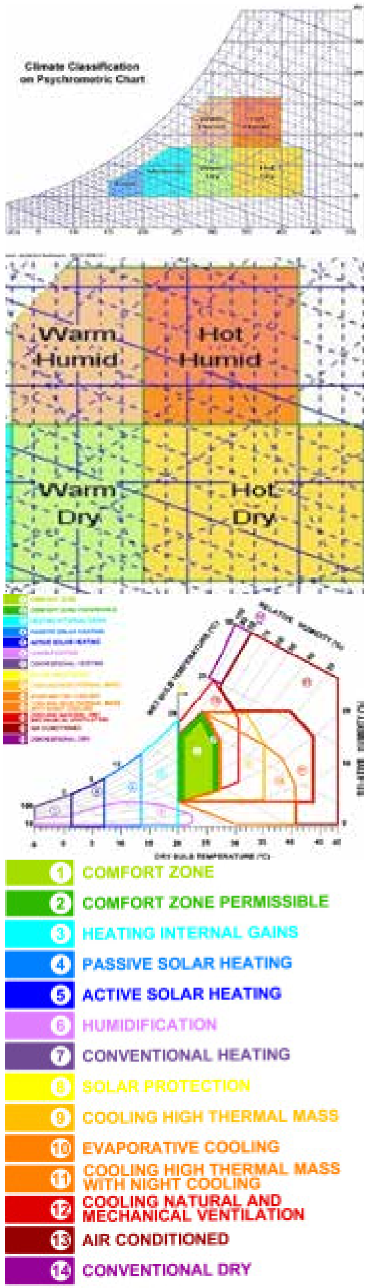
4.3.4.3.3 Movable Thermal Mass

The movable thermal mass technique is a variation of the previous one, but with an even higher cost. It requires the construction of a thermally insulated pond on the roof of the building with a movable insulation device above it. Between the pond and the roof of the building, there is a gap in which the water from the pond can be canalized.

4.3.4.3.4 Flat Plate Air Cooler

A flat plate air cooler can be used for cooling water in a loop, similar to the solar collector linked to a storage tank. This is a very simple device, looking almost like a flat-plate air solar collector without glazing. It consists of a horizontal rectangular duct. The top of the duct is the radiator, which is a metal plate. The metal plate should be covered with a material highly emissive in the long wave section of the electromagnetic spectrum, since the emittance of metals decreases with the wavelength. A windscreen can be used to protect the radiator surface from the wind effects. The various studies carried out by researchers on radiative cooling are summarized in this section. The simplest passive radiative cooling technique is to paint the roof white. White paint does not significantly affect the radiation rate at night, since both white and black paints have almost the same emissivity in the long wave range. The advantage of a white painted roof is that by absorbing less solar radiation during daytime, the temperature of the roof remains lower and can be easily cooled by radiation at night. Muselli [64] *presented a low cost new radiative coating material (1/m2) allowing to limit the heat gains during the diurnal cycle for hot seasons. He studied its reflective UV-VIS-IR behavior, and compared it with that of other classical roofed materials available in industrial and developed countries. His simulation results showed that the low cost white opaque reflective roofs would reduce cooling energy consumption by 26-49%, compared to the uncoated materials for a surface temperature of TO= 60°C."* [65]

4.4 Conclusion



[Fig-18] Climates Based on Comfort Temperature-RH Table

Which climate is appropriate to use wind and passive cooling systems by ventilation?
From the results concluded in the different studies indicated in [Fig-18], we can ascertain a general category for the different climates based on temperature and relative humidity. It is therefore evident to understand which kinds of strategies could be useful in each climate. While cold and moderate climates are not the subjects of this research, ventilation will most certainly have a very important role in hot and warm climates in the following order of importance:

- 1. One of the main objectives for **hot and dry climates,** is to utilize natural ventilation to help pull down body temperature through body evaporation and if it is under 37° C, by using convection too. We can also use ventilation with evaporation at the same time, which makes it more effective to create a cooler environment.

- 2. When there is a **hot and humid** climate, our body can experience a smaller decrease temperature by the convection and direct evaporation because of water molecules that saturated the air molecules. Thus, in this case, using evaporation could not be a very good solution. In the case where evaporation comes with a much lower temperature, water could have a good effect.

- 3. Ventilation also could have a very positive influence on warm-hot and warm-humid climates.

“The recent concept of energy efficient Green buildings attracted many scientists and building architects to switch over from the present practice of mechanical cooling to ancient methods of passive cooling methods in an efficient modern way.

It should be noted that a concept suitable for one place may not be suitable for another, if the climatic conditions are dif-

ferent. Hence, being highly site specific, based on the climatic zones like hot and dry, warm and humid, cold and sunny, cold and dry, composite conditions etc., the selection of various cooling methods, and the selection of buildings and the associated materials, has to be made. [66-77]
The concept of passive cooling for all the methods classified in this paper along with a detailed review provided under each category will be very useful for building design engineers and architects to evolve with multiple concepts for a given site, while making an energy efficient design for Green buildings." [78-82]
We can simplify "types of passive cooling techniques" to:

1. Cooling with Ventilation
- Night flush (using cold night air to pre-cool building for next day)
- Comfort ventilation (day or night, to promote evaporation from skin)
- Wind-towers (capture and expulsion)
- Indirect ventilation by Solar-chimney or Trumb-Wall or cupola

2. Radiant Cooling
- Direct radiant cooling (through roof structure, out to night sky)
- Indirect radiant cooling (heat loss to night sky transferred to a fluid that in turn cools the structure)
- Shade

3. Evaporative Cooling
- Direct evaporation (water spray at air inlet)
- Indirect evaporative cooling

4. Earth Cooling
- Direct coupling (earth embankment)
- Indirect coupling (air entering structure by way of buried tubes)

5. Dehumidification with a Desiccant
- For removal of latent heat in the humidity

6. Thermal Mass

4.5 End Notes

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PART II

Interpretation and Reflection

CHAPTER 5

Vernacular and Traditional Architecture in Hot Climate as Across the Middle East

5.1 Objective

The core objective of this chapter is to determine the main vernacular and traditional architecture methods that people used in the ancient world. Traditional architecture of hot climate areas is the result of experiences from thousands of years of civilization, where humans survived in hot climates by creating more comfortable places in which to live. Furthermore, we want to discover through our contemporary knowledge of sustainable architecture and passive cooling system strategies, how much this vernacular traditional architecture (with sustainability and passive architecture strategies) could be useful. The result of this chapter could help us to realize the main passive strategies for different types of hot climates of the past.

The first modern humans built houses to keep out the elements – rain, wind, sun, and snow. Their purpose was to produce an environment favorable to their comfort and even to their survival. [1]

"The survival of traditional societies over hundreds and thousands of years indicates that they surely possessed knowledge that can still be of great value either in its original form or as the basis for new development." [2]

When we talk about vernacular architecture of the Middle East, where the three most ancient parts of the world first began – Babylonian civilization (2300 BC), the Persian Empire (1st millennium BC), and Egypt (3000 BC), one cannot deny their enormous cultural, architectural, scientific and urban effects they had on human life. The countries which are located in this area – Iraq, Iran, Syria, Lebanon, Yemen, Saudi Arabia etc. all have a mainly hot and low rain climate. It is thus, one of the best places in the world to study vernacular and sustainable architecture in hot temperature climates and is of important significance to our study.

In this chapter, a new classification will be presented based on environmental passive architecture for “Bad-Girs.” In this classification, this element will at first, be divided based on microclimate, and then be divided into Wind-Boxes and Wind-Towers, based on their height.

5.2 Middle East

The history of the Middle East [Fig-1] is an inseparable part of human history. Ancient Sumer was the first civilization on Earth, and produced the oldest known piece of literature, the Epic of Gilgamesh, which is now over 4000 years old. In ancient Egypt (3150 – 2686 BC), we can see the first civilization of North Africa near the Nile River, where the pharaohs had built the pyramids. Babylon (2300 BC) was founded near the Forat River. Persia, now Iran, is home to one of the world's oldest major continuous civilizations, with historical and urban settlements dating back to 7000 BC. [3] The first Persian Empire was the only civilization in all of history to connect over 40% of the global population, accounting for approximately 49.4 million of the world's 112.4 million people around 480 BC. [4] It expanded from India, Pakistan, Iran, Iraq, Turkey, Greece to Egypt (500 – 600 BC).

5.2.1 Climate of the Middle East

“The majority of the Middle East region is characterized by a warm desert climate. Weather in this climate is very high during the summer and can reach dangerous levels, with parts of Iraq and Iran having recorded feel-like temperatures of over 71° C (160 ° F). Average temperatures during the summer usually rest at around 49 ° C (120 ° F), while the winters are somewhat milder. This climate also has very little rainfall, resulting in large desert regions. Areas of the Middle East surrounding the Mediterranean, such as Israel and Lebanon, instead boast a warm Mediterranean climate similar to parts of Greece and Italy, while Turkey’s territory stretches over a variety of arid and continental climates. The northern regions of the Middle East in Iran, Afghanistan, and Central Asia are closer to a steppe climate, with colder winters but still very little precipitation.

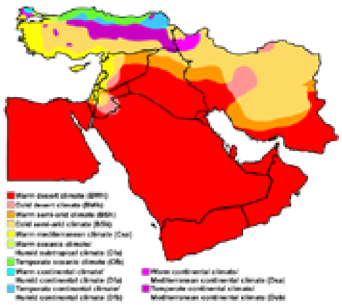
As a result of its arid climate, the Middle East is home to several of the world’s largest deserts. The Syrian Desert, which also stretches into Jordan, Iraq, and Saudi Arabia, combines both traditional desert and steppe geography, while the Arabian Desert around Yemen, Oman, Jordan, Iraq, and the Persian Gulf contains more of the rolling sand dunes which often characterize desert imagery. Indeed, the Rub ‘al-Khali, or Empty Quarter, at the center of the Arabian Desert is the largest sand-only desert on the planet and receives as little as 1.2 inches (30 millimeters) of rainfall per year. The Sahara Desert, which stretches across northern Africa and which is perhaps the best-known desert in the world, reaches into the Middle East by way of Egypt.” [5] [Fig-2]

In general, we can divide Middle Eastern hot climate to into two main categories with these characteristics:

A. Hot-Arid with very Low Relative Humidity and very Low Rainfall (Desert)

B. Hot-Arid with high Relative Humidity, Low Rainfall and some Seasonal Monsoon (located near seas and oceans)

Middle East map of Köppen climate classification



[Fig-1] Middle East Map [Fig-2] Middle East Climate Map (Köppen)

5.2.2 Vernacular Passive Architecture and Urban Strategies of Middle East in Hot-Arid, Low Relative Humidity Climate

A large part of the Middle East has a hot and dry climate, where there are many different deserts and the level of rainfall and relative humidity is incredibly low. The difference between maximum daytime temperatures and minimum nighttime temperatures is around 15 °C.

A hot dry climate is normally one in which the potential for evaporation from the soil surface and from vegetation exceeds the average annual precipitation. Drought and aridity are the main features of this climate, because, the capacity of the atmosphere to acquire water evaporated from the soil surface and transpired from plants is often greater than the water added to the soil through precipitation. [6]

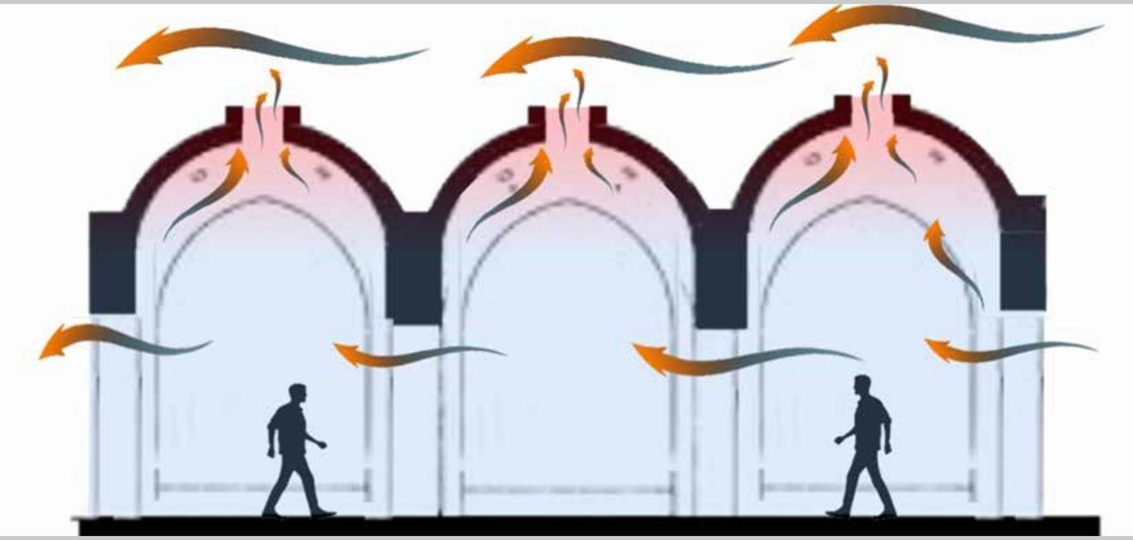
5.3 Vernacular Urban Strategies for Passive Cooling in Hot-Dry Low Relative Humidity Climates

5.3.1 Vernacular Urban Strategies in Paths and in Public Spaces

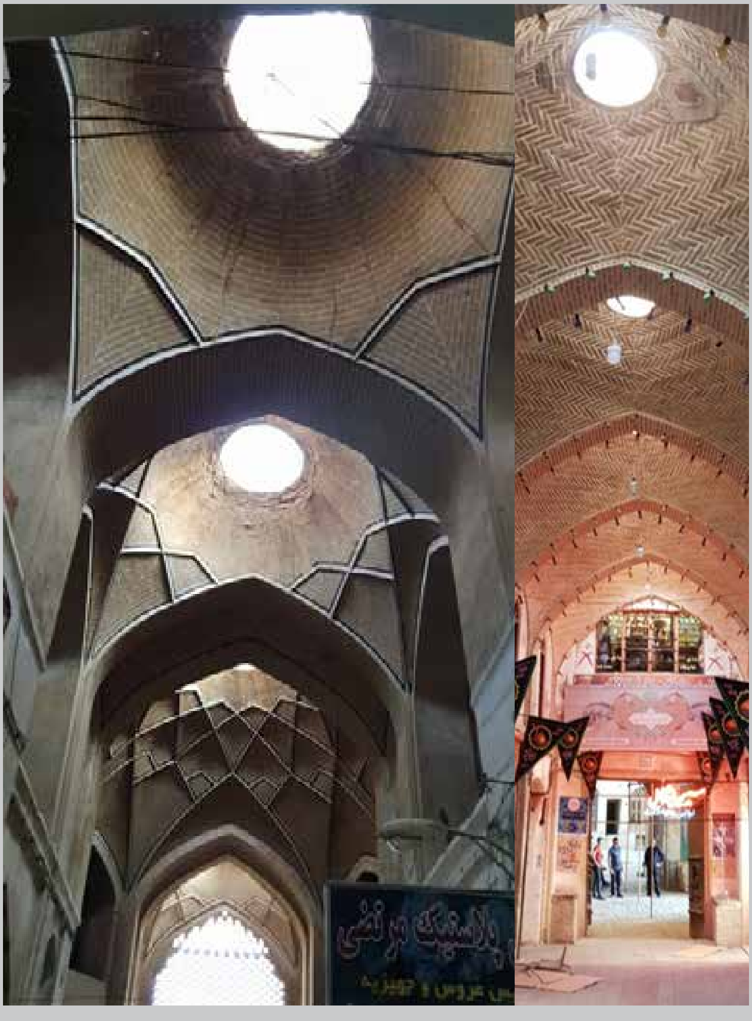
The traditional and vernacular architecture of the Middle East also took into account public spaces and had found some solutions to create a cooler public space using passive strategies. They usually incorporated narrow alleys with tall walls. In this way, the roads always had one side in the shade. In other words, it absorbed half of the day's sun radiation. [Fig-3] Sometimes, they covered alleys made with large masonry arches. We can usually find this strategy on roads with more traffic, like near the homes of famous people [Fig-4] or bazaars (commercial centers of the city). In bazaars, there are many cupolas with holes on the tops of their paths that help to drive out hot temperature areas from the top and create negative pressure on the top parts. In this way, there is always an air flow when people walk inside. [Fig-5–6]
The structure of the city is open to favorable winds and closed to unfavorable ones, particularly when the directions of the cool, pleasant, or dusty and unpleasant winds are quite distinct. [7]
In many bazaars, evaporation strategies have sometimes been used in addition to natural ventilation strategies. "Timcheh" is a part of the bazaar that features more artistic and rich decorations. These are also used for evaporation, using vernacular architecture technology. Other strategies for saving public spaces is to create as much shade as possible, sometimes using fabric or arches (Sabat). [Fig-8]
"Climate is a dominant factor which influences the evolution of urban and architectural style of hot and arid regions." [8] The compactness of the structure prevents the penetration of solar radiation. Walls and roofs are usually thick so that they protect the interiors from external heat. The structure of the city is open to the favorable winds and slightly slows down wind speed. This effect is helpful because in Deseret, there is some dusty air that is not healthy. The antique and traditional cities that are located in hot climates in the Middle East [Fig-9] or North Africa [Fig-10] usually have a compacted tex-

[Fig-3] Narrow Alley to Create More Shade on the Walls and Receive Lower Sun Radiation (Photo by: Amir Imani)

The structure of the city is open to favorable winds and closed to unfavorable ones, particularly when the directions of the cool, pleasant, or dusty and unpleasant winds are quite distinct. [7]



[Fig-5] Bazaar Section: Wind Flow, Passive Ventilation. (Copyright: Amir Imani



[Fig-6] Kashan Bazaar, Natural Ventilation (Left and Right Pictures) P hotos by: Amir Imani

[Fig-8] Top: Sabat in Yazd – More than Structural Motivation It Could Help to Create More Shade and Wind Flow. Botton: Covered by Fabric to Block Sun's Radiation.
Photo by: Amir Imani

ture with shared walls and the boundaries between the houses with narrow alleys were constructed in this way because:

- a. The water resources are in more limited places than in other parts of the world; therefore, they extended the water resources towards the direction of the city
- b. To protect the city from potential enemies
- c. To protect the city from dusty and warm ventilation
- d. To create more shade in the alleys and protect themselves from sun radiation

"This arrangement reduces the total exposed surface area and hence the total solar energy received by each house." [9]

The most important parts of Islamic cities are the mosque and bazaar. These two main elements carry an important connection together. Another important element is the cistern or natural fridge where big pieces of ice made in winter are conserved until summer. [Fig-11]

[Fig-9] City of Yazd, Iran

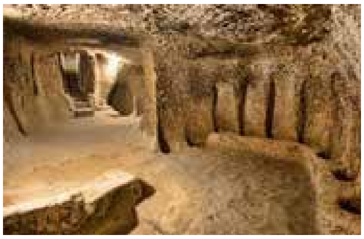
[Fig-10] The Ruins of Al Qasr, an 800-Year-Old Islamic City

[Fig-11] Ice-Pits in Sirjan, Iran

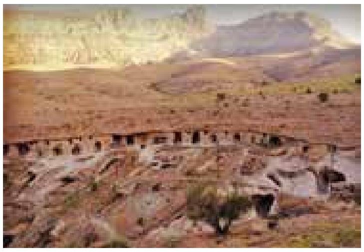
5.3.3 City Underground

Underground strategies in architecture and urban design have many benefits in saving energy because its temperature constantly is around 19 – 24 ° C. This is really close to our comfort zone in the Comfort Table. In cold or hot temperatures, this could be one of the best solutions for sustainable architecture today. It could also be a safe place for protection against nuclear radiation. However, there are also some problems with underground architecture and underground cities; for example, high humidity, low levels of water underground, resistance to top loud pressure, hard excavation, and difficulties of creating good natural ventilation.
"Going underground and the utilization of caves as living spaces by early man covered a long part of mankind's history. Throughout its history, mankind tried to prepare the needs of their tribes by using the earth in their construction in order to achieve healthy and safe spaces such as protection against harsh climate and wild animals. Cappadocia in Turkey, Setenil de las Bodegas in Spain, Nooshabad, Kariz, and Meymand in Iran and Coober Pedy in Australia are all examples of contemporary sustainable design." [10]

[Fig-12] Termites Houses



[Fig-13] Oie/Nooshabad, Underground City (500 AC) near Aran va Bidgol in Kashan, Iran



[Fig-14] Maymand Underground Village Near Kerman (Hot Climate)

[Fig-15] Kandovan Village Made by Digging Inside the Mountain, North-West Iran Near Tabriz

Sometimes ancient civilizations, in order to protect themselves from heat, cold and enemies, took refuge inside mountains or in underground places. They often looked like a giant resemblance of a gigantic termite colony. [Fig-12]

For example, the city of "Oie/Nooshabad" in Iran (500 AC) was built in - 4 to -16 M and the air-conditioning was supported by different vertical ducts connected to city wells. [Fig-13]
"**Meymand**" [Fig-14] is a very ancient village located near the city of Shahr-e Babak in Kerman Province, Iran. Meymand is believed to be a primary human residence in the Iranian Plateau, dating back to 12,000 years ago. Many of the residents live in the 350 hand-dug houses amid the rocks, some of which have been inhabited for as long as 3,000 years. Stone engravings nearly 10,000 years old are found around the village, and deposits of pottery nearly 6,000 years old attest to the long history of settlement at the village site. According to the first theory, this village was built by a group of Aryan tribes about 800 to 700 years BC. [11]
Current residents of "Kandovan'" or "Troglodyte" village in the province of East Azerbaijan, claim that their village is more than 700 years old. It was created, they say, when those fleeing the advancing Mongol army took to the caves to hide one of the most famous underground constrictions called "karan." The caves have very high energy efficient homes on Earth and they provide people refuge from the very cold winters of this area. [12] [Fig-15]
"Cappadocia in Turkey, which is located in a mountainous climate, consisting of cliff settlements such as rocky buildings, cone villages, underground dwellings and towns with redoubts and hydraulic tunnels. It is considered to be a complex structure which is combined both as underground and rocky sheltered structures. Environmental reasons of cliff dwellings have a significant value in comparison to the conventional nine buildings. The volcanic and smooth material with the natural and high potential of thermoregulation of the ground regarding climatic behavior led to the creation of a convenient shelter for its users. Stable indoor temperatures, which are approximately between 12 to 15 ° C during the cold weather of the winter season and dry summer season, provides the thermal comfort for residents. (Stea and Turan, 1993)" [13] [Fig-16]

[Fig-16] Cappadocia in Turkey

The thermal mass of a structure is the combination of the density and quantity of the building materials. Thermal mass can be effectively used in buildings to improve occupants' thermal comfort conditions. This is a major advantage and hence, this construction type is considered to be an important sector in the realm of green and sustainable building movement, low-impact design, and eco-homes, and brings harmony to its environmental surroundings, particularly in recent years. [14]

"The significant feature of earth sheltered houses is that the earth can be used as a natural high thermal mass. Thermal mass has a certain ability to store heat. When there is a thermal mass in a building, it can absorb the heat from the air or from direct solar radiation. After the storage period, the thermal mass can release the heat back to the air during the night. In an earth sheltered house, the process can be slow enough to keep the house in a comfortable thermal condition for hours without any heating or cooling. In conventional houses, in contrast, very little excess heat can be used and when the heat source is over, the heat will rapidly go away. The important benefit of earth sheltered architecture is related to energy saving through decreasing the cooling and heating loads compared with convention." [15]

"Underground buildings would be spared many of the hazards of nuclear thermal pulse. The lack of combustible facades and roofs, along with small window areas sharply reduces the hazard. If consistent with the solar design, underground buildings with windows could be oriented such that the windows face away from likely target areas, thereby eliminating the thermal pulse load. To further reduce the fire hazard, windows and skylights could be covered with metallic blinds or glass fiber draperies which will shield combustible furnishings from the thermal pulse.

Underground buildings are also spared the devastating damage which the nuclear shock-wave and blast winds would cause to ordinary buildings. When the shock-wave hits an exposed vertical wall of any building, a reflection of the shock front occurs, creating reflected pressures several times greater than the incident overpressure. The large thermal mass of underground structures allows the heating and cooling system to operate at a more constant load with a concomitant increase in efficiency. During non-work days, the heating and cooling systems can be shut down completely and the building temperature is allowed to drift slowly as heat is exchanged from the building mass and surrounding soil." [16]

"Underground buildings are pointed out as alternatives to conventional aboveground buildings for reducing total energy requirements, while alleviating land use and location problems. There is the potential for reducing the heating and cooling energy demand of underground buildings compared to aboveground buildings." [17]
"The earth temperature beyond a depth of one meter is usually insensitive to the diurnal cycle of air temperature and solar radiation and the annual fluctuation of the earth temperature extends to a depth of about ten meters. In order to study the fluctuations of the ground temperature with depth, we have installed a 50-meter-deep U-tube in the ground equipped with thermocouples at various depths. The measured temperatures indicate that the short-period temperature variations are prominent to a depth of approximately 0.5 meters. Because of the high thermal inertia of the soil, the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases. The annual temperature variation of the ground at a depth of 3 meters is between 15 to 25°C while at a depth of 25 meters is negligible and the temperature remains constant at about 22°C. The temperature measurements are compared

5.4 Vernacular Architecture Strategies Passive Cooling in Hot-Dry & Low Relative Humidity Climates

5.4.1 House with a Central Courtyard

"One of the most successful samples of climatic responsive architecture is traditional courtyard houses in the hot climates of Iran, which were designed with careful attention to the climatic requirements and socio-cultural contexts. Moreover, the central courtyard itself is one of the most effective elements. It can be defined as a room in the center of the house. It has no roof but generally has a paved section, pool, many trees and flowers to create a self-sufficient microclimate." [19]

In effect, this typology of housing with a central courtyard is one of the most important techniques of vernacular passive architecture in hot climate areas like the Middle East and particularly in Iran. This style of passive architecture has been used for more than a hundred years as the typical ancient Iranian architecture and housing. The concept of a rectangular central courtyard creates four places (rooms) in four different sides of the central courtyard that have been dedicated to be lived in four different seasons. For example, on the northern side, "Zemestan-Neshin" was dedicated for wintertime to receive more sunlight during the day and the southern part "Tabestan-Neshin" where we can also usually find "Iwan," have been used as the summertime part of the house, where it generally receives lower levels of sun radiation and has a higher ceiling height. According to sun and earth movements, this kind of sustainable architecture encourages the landlord and his family to spend more time in different sides of the house, depending on the season. In other words, a small seasonal immigration takes place inside their house throughout the year.

The main objectives in selecting a suitable building orientation are to minimize the impact of the sun in the summer, reducing the internal daytime temperatures, and to maximize the solar impact in winter. A north–south orientation is therefore preferable to one that is east–west. [20] However, Bonine (1980) states that the orientation of houses in Iranian settlements is not due principally to climatic factors, and that the exact direction of the courtyards is based on an orthogonal network of lanes and water channels that have been laid out in the direction of greatest slope to irrigate cultivated fields and orchards. [21]

"The courtyard (Hayat-e-Markazi) in a hot dry climate is usually the heart of the dwelling spatially, socially, and environmentally. Although, the size of the land, to some extent, is influential, the average size of the courtyards is generally determined according to the latitude. They are narrow enough to maintain a shaded area during the heat of the day in summer, but wide enough to receive solar radiation in winter." [22]

"Considering a courtyard with a number of rooms around it, the southern wall of the courtyard is the most shaded area all through the seasons. The room behind this wall is very cold in winters but, the most preferred area to live in summers. Shade is provided more in smaller courtyards than in larger ones. Roofs are provided with parapets as high as one to two meters, which further provide shade on roof surfaces." [23] *"The courtyard climate is similar to the climate on the roof and in one large courtyard (10 M x 14 M) measured only at around 2 am to 6 am were average courtyard temperatures higher than recorded roof temperatures."* [24]

5.4.2 Iranian Central Courtyard Elements (Hayat-e-Markazi)

A complete and perfect Iranian house has at least two rectangular courtyards. Because of Islamic culture in this area, houses have been divided in two main parts: [Fig-17]

- **"Anraruni" (Inside)** where the landlord and his close family (i.e. children, parents, wife or other close relatives) live. In this area, the women could have their hair exposed (no need for a scarf).

- **"Biruni" (Outside)** where the family members, mostly husband and wife, meet other people and spend time with their guests, friends or have commercial meetings.

[Fig-17] Andarooni and Biruni in Persian Central Courtyard House. Picture by: Ahad Shahhoseini

5.4.2.1 Position Considering the Sun Movement and Radiation

It is evident that one of the sustainable architecture techniques in the world that has enabled habitats to be more comfortable is the central courtyard. Normally, houses in central Iran have central courtyards with an orientation of N / NNW, in order to have the best receiving sun radiation in winter in the northern part, and their shaded parts are usually where their Wind-Towers are located. [Fig-18]

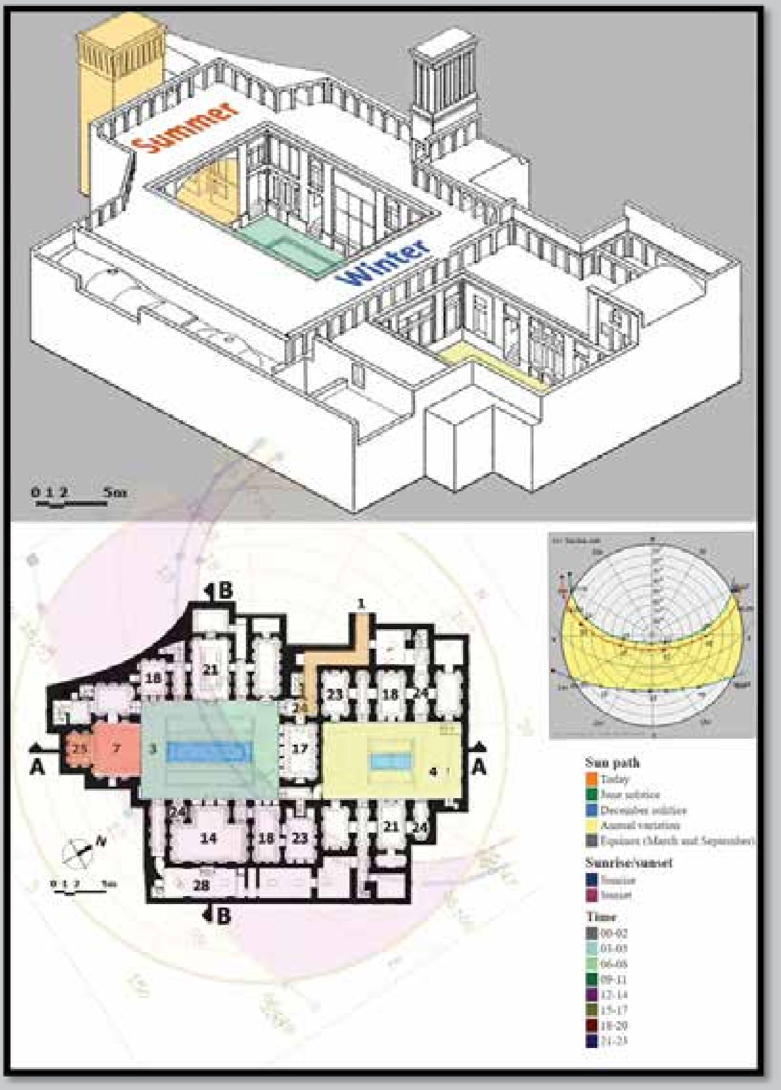
Central Courtyard Houses with Passive Cooling Architecture Elements

Central courtyard houses use different passive cooling techniques separately or in combination.

- Shading: high walls, arches, trees, Godal-Baqcheh, colored doors and glass windows.
- Ventilation: Wind-Tower, cupola, aperture (doors and windows), Ashudan
- Evaporation: courtyard fountain, underground fountain, indoor fountain, trees, Qanat
- Thermal-Mass: entire building, underground cool temperature, thick clay walls, wind-tower
- Night-Radiation: entire building, cupola

5.4.2.2 Central Courtyard

A Central courtyard can provide security, privacy, and a comfortable place within the house. The courtyard, usually planted with trees, flowers and shrubs, not only provides comfortable conditions and a beautiful setting, but also supplies some shade and increases the relative humidity of the courtyard space. [25]
Normally, the courtyard has a lower temperature than the rooftop because some part of it is always in the shade. While the sun moves between 12pm and 3pm, usually the courtyard has a higher temperature than the roof because on the rooftop surface, there is more wind movement than in the courtyard. Therefore, the roof can lose more heat. It was found that in summer, most



[Fig-18] Courtyards Biruni: 4 and Andaruni: 3, Iwaan:7, Dalan:1, Direction Traditional Iranian House, Yazd (Graami House)

of the time, the non-shaded courtyard is warmer than the ambient air temperature near the house, day and night. In a few cases, the temperature differences between the ambient air and the air inside the courtyard were as high as 7°C. In winter, the temperatures of the courtyard were somewhat moderated compared to the ambient, but even then in most cases, the courtyard was warmer than the ambient air. [26] *“The courtyard climate can also influence the performance of the wind catcher, because air for the wind catcher is drawn from two areas, from the roof and from the courtyard.”* [27]
The main elements of the courtyard are:

- Fountain
- Vegetation
- Tree

By nightfall, the courtyard surfaces, which are made of materials with high capacity for storing heat, including its floor, surrounding walls, and the earth beneath, are much hotter than the sky since during the day, they soak up and store considerable quantities of heat, making these surfaces main heat sources in the courtyard. Accordingly, heat exchange between the courtyard house envelope and its environment commonly occurs through two modes, namely convective heat transfer and radiant heat exchange. Regarding convection, because sky cooled air has very high density, it sinks down and accumulates inside the courtyard, especially close to the ground. [28]

5.4.2.3 Courtyard Fountain

[Fig-19] Fountain in Central Courtyard a House in Yazd Photo: Amir Imani

The most important element in the courtyard of Iranian houses is the fountain, [Fig-19] especially in hot and dry temperatures. The central fountain, located in the center of the central courtyard, is in symmetry with axes. The depth is less than 70 cm, the color is blue or the color of the stone it was made with. The fountain has been used for: [Fig-20]

- Decreases the courtyard temperature through evaporation
- By wetting the courtyard floor in the late afternoon, the floor loses heat and cools the air temperature in a part of the courtyard
- For daily hand and face washing

- For washing the dishes
- For washing fruit, vegetables and other foods
- For watering plants and trees
- Creates a relaxing ambience
- Creates a mirror effect and reflection

Passive cooling effect of a fountain in architecture:

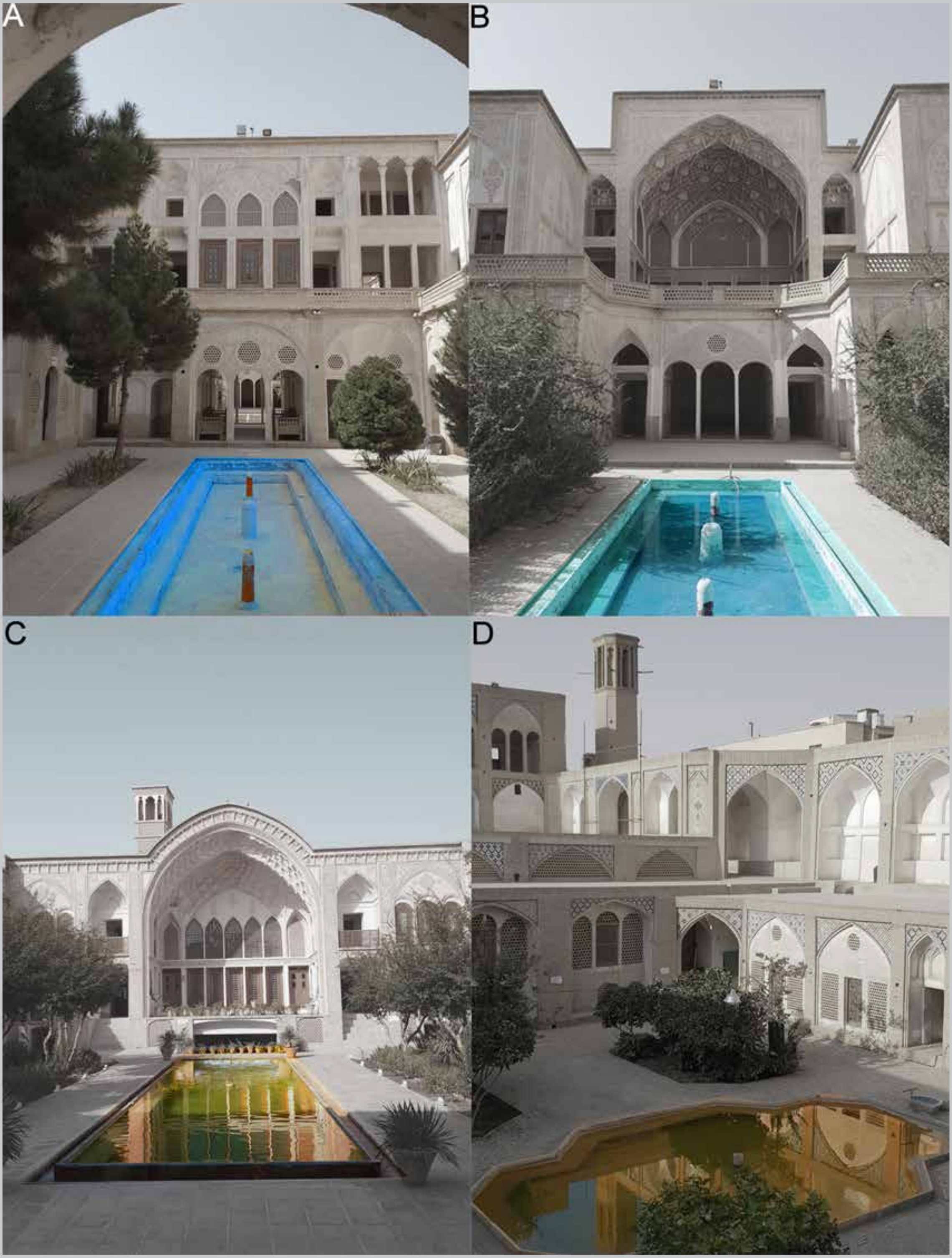
- Reflection of sun radiation, in other words, lowers reflection
- Evaporation
- Evaporation accompanied with natural ventilation
- High heat capacity can absorb heat and release it during the night

5.4.2.4 Roofs

The roof is another important element in traditional architecture, as it is the main part of the building that absorbs maximum direct radiation from the sun during the day, and at night, as a radioactive mass transferring heat radiation to the sky. Based on a study by M. Dabaieha and O. Wanas (2015), alternating roof shape, roof material and construction, the result of using a vault roof with high albedo coating shows a fall of 53% in discomfort hours and saves 826 kWh during the summer season, compared to the base case of the conventional non-insulated flat roof in typical Cairo residential buildings. It is recommended that the selected cool roof solution be combined with natural ventilation to increase the indoor thermal comfort, and with passive heating strategies to compensate the increase in heating hours. The application is intended for low cost residential buildings in a hot dry climate.

5.4.2.4.1 Flat-Roof

Flat-roof is one of the simplest types of roofs. In cold climates, they are usually made of wooden beams and then covered by other layers consisting of pieces of wood and then covered. In hot and dry climates however, they are different – they are made of bricks and clay, then covered and finished by a thick mass of hand-pressed clay. It is worth mentioning that in many central cities in Iran like: Yazd, Ardan, Meybod, Kashan, etc., traditional architects used a sandwich flat roof with arch forms for the ceiling under it. They used some



[Fig-20] Fountains A, B) Abbasiha House Kashan C) Ameriha House, Kashan D) Aqa-Bozorg Masque, Kashan. Photos by: Amir Imani

masonry holes between these two layers to create a perfect thermal insulation by blocking the air inside the holes. This technique also is used to lower the pressure and load of the roof on its side-walls and columns. [Fig-21]

"The roof in a typical courtyard house is flat and has a small parapet wall, slightly higher than standing eye-level, surrounding the edge of the roof. This is not only to ensure the privacy when it is used as a sleeping area at night, but also for protecting the area from direct solar radiation for a long period of day time. The roof space is used as a place for sleeping, and as a place for socializing in the evening, because not only is this area exposed to the clear sky, but it is also further away from the walls of the house, which continues to irradiate heat from the day's exposure." [30]

[Fig-21] Insulant Holes Between Flat Top-Roof and Arch Ceiling. Photo by: Amir Imani

5.4.2.4.2 The Cupola

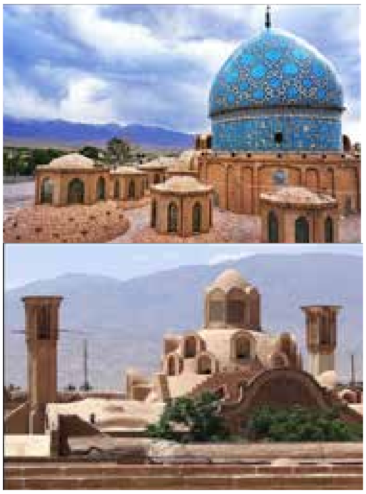
Cupola is one of the first methods used to cover roofs. This technique was used by the Romans and Persians thousands of years ago. Cupolas can be found in mosques, houses, cisterns, bazaars, sanctuaries, ice pits, schools etc.

There are four typologies of cupola openings: [Fig-22]

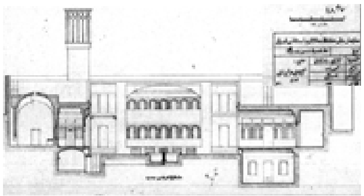
- Closed with no hole
- Open with one hole on top
- Open with different holes
- Open with one other little cupola over the hole

Another important point in roof cupola typologies in hot climates is that houses use one layer cupolas [Fig-23] but for mosques, past architects applied two layers, which makes the cupolas more resistant and insulates people from thermal heat and noise. The two layers also creates an acoustic effect inside the mosque. [Fig-24]

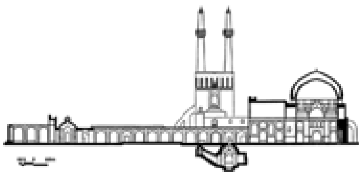
- One layer – house
- Two layers – mosque



[Fig-22] Top: Sanctuary of "Shah Nematoloah-E-Vali in Mahan, Closed and Covered Open Cupolas. Bottom: Borujerdiha House in Kashan Cupola with More than One Hole



[Fig-23] Section of Lariha House,Yazd, Iran. Cupola with One Layer, Doc. From Cultural Heritage of Yazd.



[Fig-24] Section of Yazd's Major Mosque's Two Layer Cupola

The Passive cooling strategies of cupolas:

- The cupola form creates nearly half of the shade in the afternoons and mornings. It could also create shade around the roof surface (lower direct radiation).
- The cupola form results in a maximum nighttime radiation from building to sky.
- It accumulates the heat from the top of the cupola, making cooler air run down to the interior living spaces.
- If the cupola has a hole on its top parts, then warmer air rises up and goes outdoors because of the convection effect and difference of pressure between the bottom and top of it.
- The aerodynamic form of the cupola increases wind speed in the higher points of the cupola and based on the Venturi rules, it creates a vacuum effect there. In this way, it could help the expulsion of the interior warm air move towards the outside. [Fig-25]
- Thermal mass could absorb a lot of heat during the day and relies on it during the nighttime.
- The aerodynamic form leads rising air to rise easily towards the top direction. Curvy forms have lower friction than angular forms.

5.4.2.4.3 Arch Form Roof

Arch-form roof is another ancient strategy for creating a solid and resistant structure used for many years by different civilizations – Romans, Persians, Greeks etc. [Fig-26]
The following are passive cooling strategies of arch-roofs:

- This type of roof sometimes also has a hole on top and if the wind's main direction is perpendicular to the length of the building by the Venturi effect, it could create a negative pressure on top and push out the interior's warm air.
- The arch form is also a good form for night radiation.
- They usually have two layers and between the layers, the blocked air in holes makes a good thermal insulation for heat.
- The curve aerodynamic form of the arch helps to have better air circulation inside the rooms.

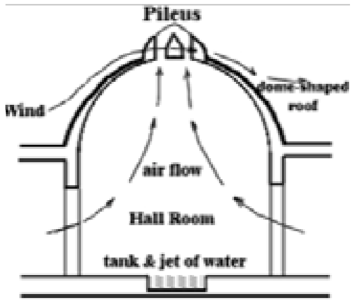
5.4.2.5 Iwan (Semi – Open Part of the Tabestan – Neshin)

Iwan – the large semi-open archway in the southern part of the courtyard is where ancient peoples lived and spent their time during the summers. Generally, the houses were attached to Wind-Towers in direct or indirect ways. [Fig-27] Iwan could have aperture/windows. This possibility could be useful in order to have more control on airflow. This part is higher than other parts of the building, and sometimes it could have two floors along with a fountain in the central part. However, this phenomenon has only been seen in wealthy people's houses.

- The position of the Iwan in the southern part of the house protected this part from direct sun radiation in the summer heat. (There was shade almost all of the time).
- The height of the ceiling in the Iwan is higher than other parts of the home, so it helps to accumulate heat in higher levels far from the human body.
- It works as a thermal mass too, absorbing the nighttime cool temperatures and releasing them in the morning.
- Large open faces towards the central courtyard increase the Venturi Effect in Wind-Towers.
- The Iwan floor is connected to the underground floor that has the lowest temperature in the home (people used to sit on the floor over the carpet or cotton thick fabric).
- At night, when the wind-tower works as a chimney, it receives fresher air from the courtyard and absorbs the cooler temperature inside its mass.

5.4.2.6 Material

In this area, all of the traditional buildings have been built by adobe (raw clay) or brick adding straws. [Fig-28] The walls are wide, around 50 – 90 cm, and this combination conserves cooler night temperatures inside the home walls and roof while at the same time, it protects the space from the outside heat. Interior finishing is usually made by plaster. Windows and doors are now made of wood and color-glasses decoration. We can also find wood as columns or some parts of the structures of Wind-Towers. Because of the characteristics of hot-dry climates, using materials with a high thermal expansion factor is not the right choice. Instead, using materials with high heat capacity like clay, adobe, wood, and brick are more beneficial.



[Fig-25] Air Flow from Down to Up and Expulsion System of the Open Cupola

[Fig-26] Kharanaq Village, Near Ardakan, Arch-Roofs

[Fig-27-A] Iwan in Aqazadeh House Abarkooh, Photo by: Amir Imani

[Fig-27-B] View from Inside Iwan to Courtyard Borujerdiha House, Kashan.
Photo by: Amir Imani

[Fig-28] Clay + Straws + Water + Hand Pressure.
Photo by: Amir Imani

In traditional architecture in hot and dry climates in Iran, to save time and cost of masonry material, they dug the area of constriction. This is the reason that courtyards usually have a lower height level in comparison to other parts of buildings. Also, traditional architects have been using raw clay from underground floors as well. [31]

5.4.2.7 Material Covering the Central Courtyard

One of the other passive strategies is covering the courtyard bay with large pieces of fabric and ropes to receive lower amount of direct sun radiation in the courtyard. [Fig-29]

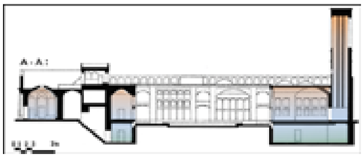
5.4.2.8 Underground Floor (Sardab)

The underground floor is the cooler part of the traditional house in hot and arid climates, where people conserve food and fruits. It is connected to the courtyard with little perforated windows to provide air circulation and a weak natural light. Many people who lived in the area used to spend the hottest time of day here to stay cool. [Fig-29]
In many houses in Yazd and Kashan, the underground floor has an internal fountain, which can also make it cooler through evaporation.
Sometimes there is a connection between the Iwan and the underground floor under the Wind-Tower (Bad-Gir). This technique, through the vacuum effect that is made by the air flow of the Wind-Tower over the hole, expulses out cool air from underground and brings it to the Iwan.
There are some other examples where Wind-Towers use long canals around underground walls and fresh air comes out in the Sardab instead of the Iwan (Borujerdiha House, Kashan). [Fig-30]

The passive cooling strategies of underground floors have:

- Lowest sun radiation levels
- Convection with low temperature underground mass. Underground floor has a connection on five sides with the part, and has a stable temperature of around 20 – 24 °C all year
- Evaporation, if it has a fountain or connection with a Qanat (acquaintance underground water)
- Improvement in the operation of the Wind-Tower
- Cool mass

[Fig-29] Covering the Courtyard Photo by: Amir Imani



[Fig-30] Emprature Level in a Traditional House

5.4.2.9 Godal – Baqcheh (Underground Courtyard)

Godal-Baqcheh is a courtyard in a lower level (level of underground floor) that gives natural light to the underground floor. Because it is deeper compared to a normal courtyard, it has lower sun radiation and can enter lower than normal courtyards, and there is more shade. Thus, this place also has a cool temperature. [Fig-31]

The difference between the effect of fountains in normal courtyards and fountains in Godal-Baqcheh is that the cooler air by the evaporation effect accumulates in downward levels and lower height levels make more shade, and wind has a lower effect on transferring the air molecules. [Fig-32]

The passive cooling strategies of Godal-Baqcheh are:

- Lower sun radiation level
- Evaporation by fountain
- Saving electricity energy by giving an indirect lighting to underground floor

[Fig-31] Top: Underground Floor Fountain in Yazd. Bottom: Connection Between Underground Floor and Iwan Under the Wind-tower, Yazd. Photo by: Amir Imani

[Fig-32] Godal-Baqcheh Yazd (Pardis-e-Memari).
Photo by: Amir Imani

5.4.2.10 Wind and Architecture

In this study, the historical architectural elements which are supposed to capture or expulse wind flow into or out of traditional buildings are classified into two main categories based on their height:

- Wind-Box: the opening is almost attached to the roof
- Wind-Tower: the opening is located at least one meter (1M) higher than the roof

Ancient people, through time and experimentation, learned how to use main natural elements to create more comfort (water, soil, wind, fire). They then created architectural and engineering elements to increase the airflow in their houses.
Hundreds of wind catchers and courtyard houses still exist in the old quarters of cities such as Yazd, Ardakan etc., and they are significant sources for contemporary research on sustainable architecture or zero energy housing. This form of housing can also be used in the architecture of today. It could also be a reference for new development in other subjects and in combination with new technological instruments, it could present an innovative solution for construction fields. [32] [Fig-33] tries to present e general vision of the different forms and typologies of Wind-Towers and Wind-Boxes on the Middle East map.

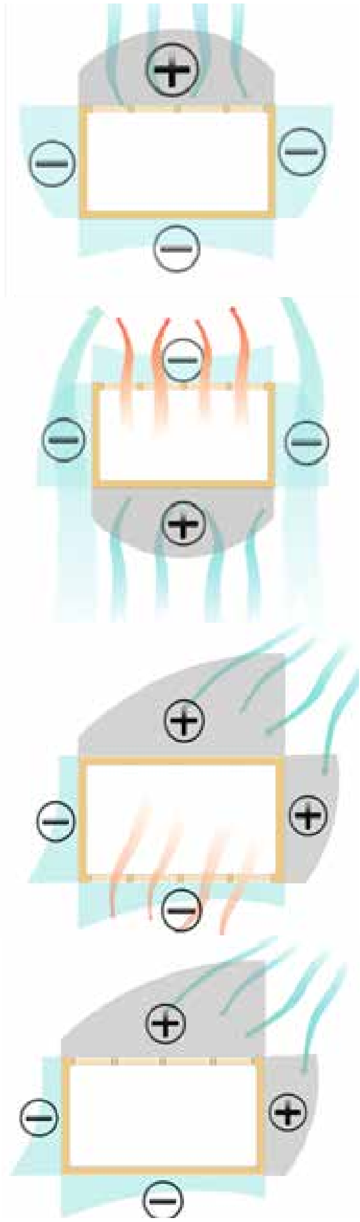
5.4.2.10.1 Wind-Boxes

Other research conducted by M. Kazemi Esfeh, A. A. Dehghan, M. Dehghan Manshadi, and S. Mohagheghian, resulted in three forms of flat openings. For inclined and curved heads in one-opening Wind-Boxes with a velocity of 10 m/sec, the measured data revealed that around a 7% and 15% increase in the flow rate is achieved for steep or inclined and curved roof wind catchers in comparison with the flat roof type. [33] Esfeh, Dehghan, Manshadi, and Mohagheghian visualized flow structures around and inside the one-sided wind-catchers.

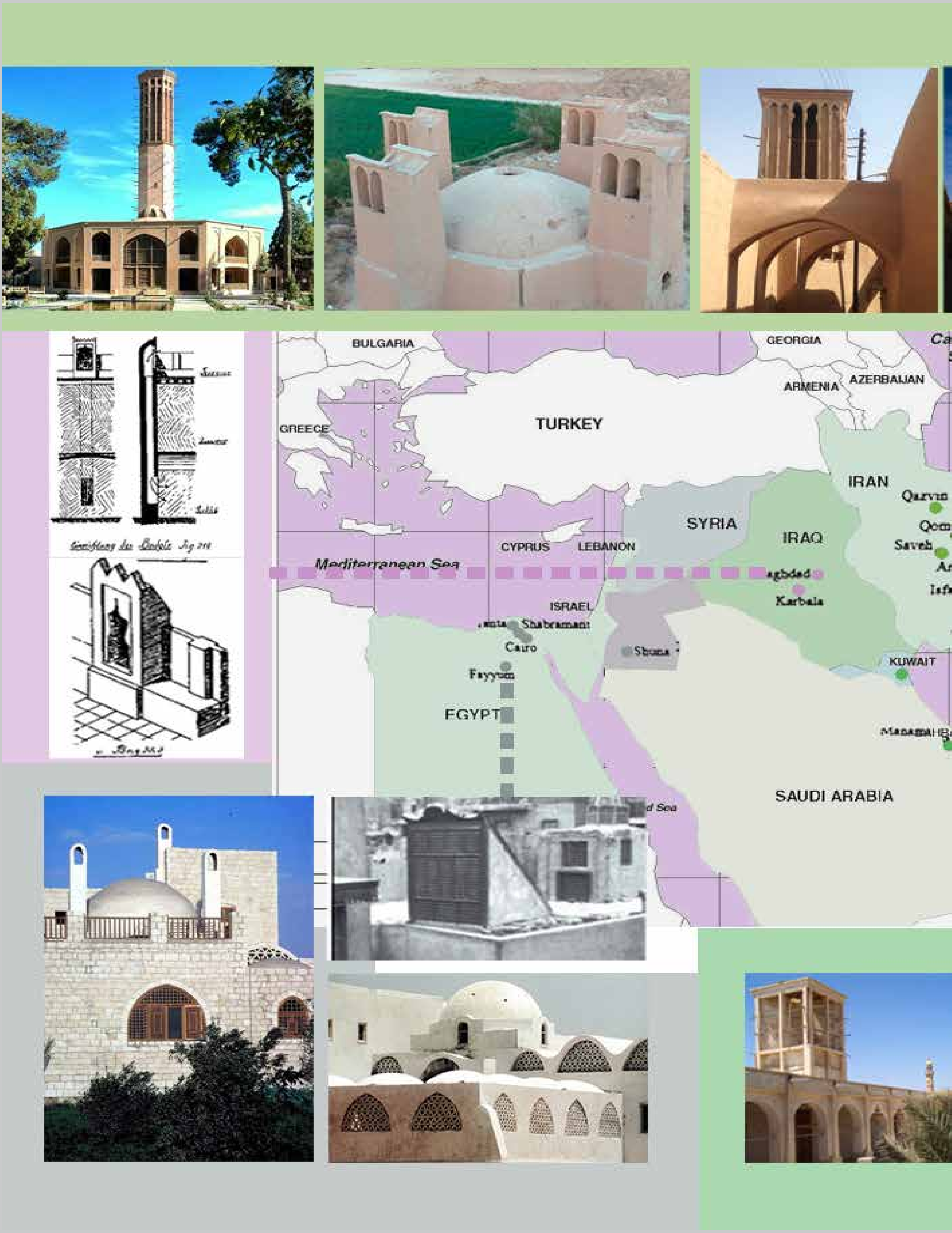
Wind-Boxes mostly have one opening. They were designed for the places that have generally just one principal direction. This means that they are not very well adapted for the regions where wind direction changes at every single moment.

Capture and Expel (Expulsion) Wind-Boxes

- Capture: If the direction of the main wind is towards the opening direction (favorable wind).
- Expulsion: If the main wind's direction is towards the back of the opening; in this way, the inclined part increases.
- Wind velocity and creation of higher negative wind-pressure in front of the opening; thus warm interior air comes out from the Wind-Box opening. If the wind blows from a diagonal direction, the Wind-Box could capture or expulse the air but will not have very high performance. [Fig-34]

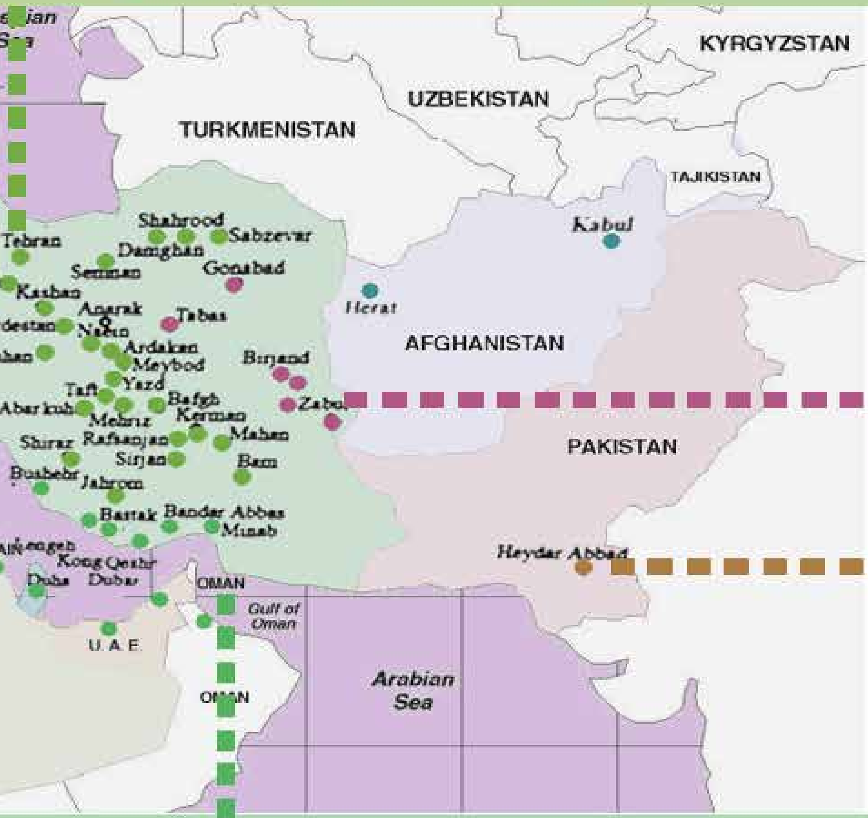


[Fig-34] Plan of Wind-Boxes and Analysis of their Behavior by Different Directions Wind Flow Aerodynamic (Copyright: Amir Imani)



[Fig-33] Different Typologies of Wind-Towers and Wind-Boxes in the Middle East (by Amir Imani)

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Kabul
Herat
Anarak
Tabas
Naein
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Taft
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Zabul
Abarkuh
Mehriz
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Shiraz
Rafsanjan
Mahan
PAKISTAN
Sirjan
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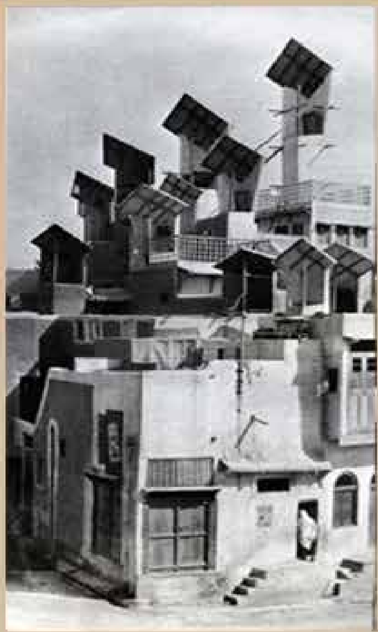
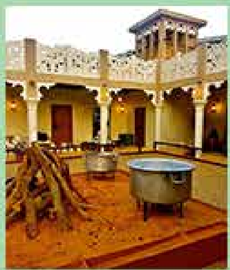
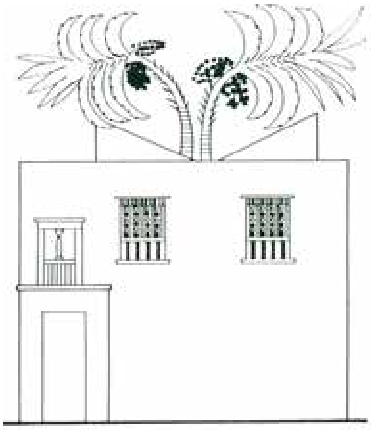




[Fig-35] Left: Image on Papyrus in Egypt New Kingdom Tomb [36]
Right: Modern-day Malqaf in Egypt

Typologies of Wind-Boxes in the Middle East:

- Malqaf – One-Opening Wind-Box (Capture)
- Iraqi Wind-Boxes (Capture)
- Wind-Boxes of Herat, Afghanistan
- Iranian Wind-Boxes – East (Wind-Box on Cupola)
- Iranian Wind-Boxes – Central-North-East (Wind-Box on Cupola)
- Iranian Wind-Boxes – Central (Bad-Gir-e-Ardakani) (Capture-Sepulture)

5.4.2.10.1.1 Malqaf – One-Opening Wind-Box (Capture)

Malqaf is essentially made of wood and has one side opening with two doors. Wind-Boxes have a dimension of around W: 2 M x H: 2.6 M x L: 2.5 M and have an inclined roof. An Egyptian wind catcher consists of a simple shaft rising above the building with a windward opening most often facing the north westerly winds. The top is covered with an inclined plate (about 30°) to lead air into the shaft. [34] Undoubtedly, one of the most ancient Egyptian strategies for Wind-Boxes is the “Malqaf.” [Fig-35]

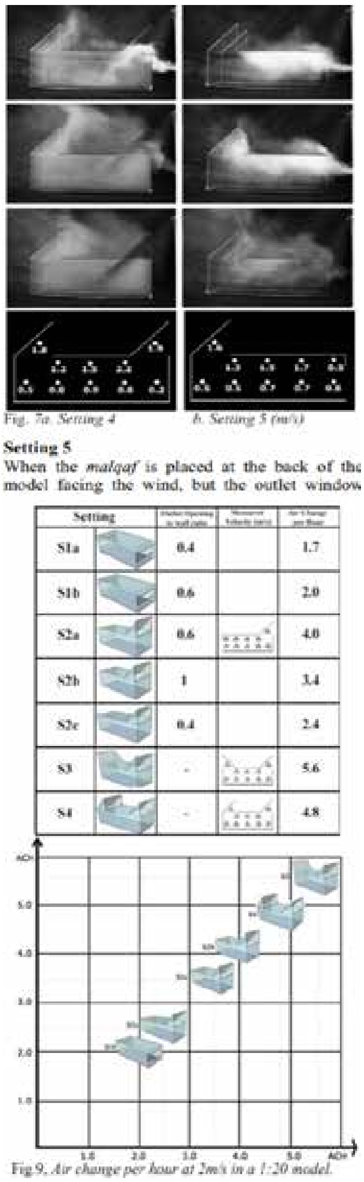
“The malqaf or Wind-Catcher has been around in Egypt as early as the pre-dynastic period, where a vent of some nature faces north to catch the cool prevailing winds. This traditional Arabic element has been used successfully in low-rise housing for centuries. The malqaf has been used as a viable solution to ensure natural ventilation by allowing cooler air movement, allowing sufficient lighting, avoiding offensive glare and reducing the sand and dust in prevalent winds” [35] (based on a study by Shadi Attia). [Fig-36]
If the interior space has two Malqaf, the airflow of the two opposite ends of the room has more velocity.
“*One example of a wind catcher is seen in a painting of the walls of the Amun tomb, one of the Middle Egyptian kings, and these elements may be the staircase leading to the roofs according to what Roaf has mentioned.* [37] *The research that has been done on the history of wind catchers confirms that they date back to BC times, but it is difficult to verify who invented them first. Due to the fact that the images of Egyptian papyrus are from 1500 BC, so as to refer to the explorations in the Flint Hills, the background of wind catcher construction in Iran refers back to 4000 BC, according to research from north of Shahrood. Asince such a record does not exist confirming any use of wind catch-*

ers anywhere else in the Middle East. Regarding the Iranians' use of wind catchers prior to the Arabs, two reasons are emphasized. First, in ancient Arabic poetry, the lyrics from Badhanj Bazehanj are used and although these are Persian words and are considered literature from the fifth century AD onwards, it can be said that the way it was built was also brought to the Persian Gulf from Iran, and they were called Bajir, which is the shortened word for wind catcher, according to the application of the Persian word for this structure. Second, the wind catchers of the Emirates are in the Bastak areas, which are predominantly in the region of the UAE where Iranians first inhabited. Other points discussed in this paper suggest the Iranian use of a ventilator before Arabs in the Persian Gulf, which is a sign of the creativity and ingenuity of Iranian architects. Thus, it can be said that the Iranians have been the source of inspiration for other countries in the field of wind catcher design as well as other innovations in the field of architecture." [38] [39]

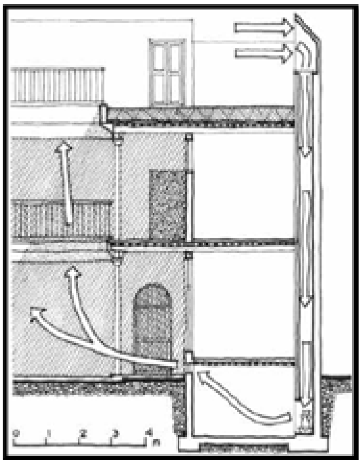
The malqafs were used by the Egyptians in the houses of Tal Al-Amarna and is represented in wall paintings of the tombs of Thebes. One example, shown in figure 1a, is the Pharaonic house of Neb-Amun depicted on his tomb, which dates back to the 19th Dynasty (1300 BC). It has two openings, one facing windward and the other leeward, to evacuate the air by suction. [40]

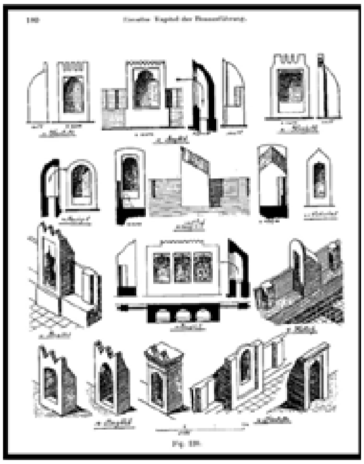
5.4.2.10.1.2 Iraq Wind-Boxes (Capture)

Wind-Boxes in Iraq are connected with a long interior duct to the underground floor. Sometimes they used pottery jars of water underground or on top of the entrance of the opening; to humidify the air and also make the area cooler by evaporation. We could find this typology of Wind-Boxes in the cities of: Kufa, Baghdad, and Karbala in Iraq. In Iraq, the main passive cooling strategies are used to cool underground thermal mass and bring the outside fresh air into this area. [Fig-37]
Wind-Boxes in Iraq are not big and mostly, they are located in the short walls around the roof with a short distance from roof floor "*duct width is 15 to 60 cm. They do not rise up high... the difference between the Egyptian Malghaf and the Iraqi Malghaf is that the Iraqi one has a 45° top part and it reaches the underground floor.*" [41] [Fig-38]
Wind-Boxes generally have just one-opening but there were some



[Fig-36] Result of Analysis of (Shadi A) Two Malqafs for Higher Speed and Better Flow





[Fig-37] Wind-Box in Iraq

rare examples of Wind-Boxes with two openings only found in Iraq. *"In Iraq, wind catchers are simply a hole in the thick mud brick or adobe walls on the roof for the summer living rooms and are built to the northwest in order to take the prevailing air and make the air cooler. Vertical pillars which are placed in these walls are the connecting openings (fans) of the roof with the basement."* [42]

"Wind catchers in Iraq are very similar to Cairo Malqafs. Some are designed with one opening on top in a rectangular plan. Wind catchers have a rectangular plan shape in Iraq. The width of wind catcher pillars are between 15 and 60 cm. Wind catcher channels do not rise far above the roof and wind catcher vents begin from the floor and do not go higher than a height of about 0.5 m to 1.20 meters. The difference between them is that the channel roof is made of 45 ° curved shape while the roof of Mokalaf is not curved. Iraqi wind catcher locations are generally on the edge of the roof and service their basement space.

Pillars are often terminated in inside shells of basement walls. The hot and humid wind that comes into the wind catcher flows in a variety of indoor space, and goes out from openings which are like open metal, small windows in basements which are located into the yard" [43] [44]

5.4.2.10.1.3 Wind-Boxes of Herat, Afghanistan

"The wind catcher in Herat, Afghanistan, is a very simple wind scoop which is located on the domed roof for almost every room with a maximum height of 150 cm. It is a small squared scoop with usually one windward opening, facing the northern prevailing wind." [45] [46] [Fig-40]
The vernacular architecture of eastern Iran is one of the basic typologies of human construction built (one room, door, and cupola). The people are mostly impoverished and they live in hard living conditions, having no access to water etc. Human history in this area dates back to around 2000 BC. There is a considerable microclimate influenced by Lake Hamuon and predominant winds that last for 120 days (June – September). The temperature from May to September is over 30°C with a maximum temperature of 50° C. [Fig-41]
"This type of Wind-Box is similar to Afghan Wind-Boxes. Actually they are located in Sistan – the Sistan region (30°5′N – 31°28′N and 61°15′E – 61°50′E). [Fig-42] *in southeastern Iran is located close to*

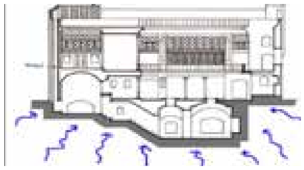
the joint borders between Iran, Pakistan and Afghanistan. [47] Sistan has a hot arid climate with an annual average precipitation of 55 mm occurring mainly in winter (December to February). In summer, and specifically in the approximately 120-day period between June and September, strong northern winds called "Levãr" in its native language, also known as "120-Day Winds" [48] affect the area, passing over Hamoun Lake and spreading its humidity across the region. It also causes frequent storms of great magnitude and velocity due to recent droughts. [49] Winds blow from the north and northwest to the southeast with an average speed of ~32 km/h. [50] The vernacular architecture of Sistan is not an exception to this rule; it uses different elements and mechanisms to overcome the climatic conditions and provide the dwellers with a comfortable living environment. [51] [52]

To deal with the harsh outdoor conditions such as heat storms, frost bites and wind flow with sand dunes, this method of construction has been able to create a suitable indoor environment and continues to do so." [53]

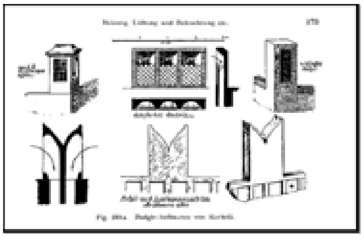
"Vernacular architecture of the hot-arid-windy region of Sistan exhibits its own set of defining aspects. [54] [55] It is generated from a single cell room (called "khoná" in its native language) and is mainly affected by two factors: 120-Day winds and the presence of Lake "Hamoun." [55] [57] Native masons of Sistan have come up with innovative solutions and elements in response to these factors to reduce the energy consumption, utilize natural ventilation, provide a comfortable setting and shape a sustainable method of construction." [58]

Wind-Boxes of Eastern Iran (Wind-Box on Cupola) Elements: [Fig-43]

"Three different ventilator openings were identified in Sistan vernacular architecture: (1) Kolak; (2) Surak; and (3) Daricheh, none of which is documented elsewhere in the country. The fact that prevalent winds (120-Day winds) are constantly blowing in hot months of the year has lead the native people of Sistan to manipulate the winds through special openings in their houses' walls and roofs. These openings let the cool wind in, naturally ventilate the interior space, and provide these spaces with fresh air and play an important role in the hygiene of the dwellers. Kolak (Kōlaḱ) is the native Wind-Catcher of Sistan. Wind-Catchers in other regions of the country are normally tall structures over the building roofs, working as a canal to direct the wind into the building through an opening in the roofs. However, in Sistan, 120-Day winds blow in lower near the ground." [59]

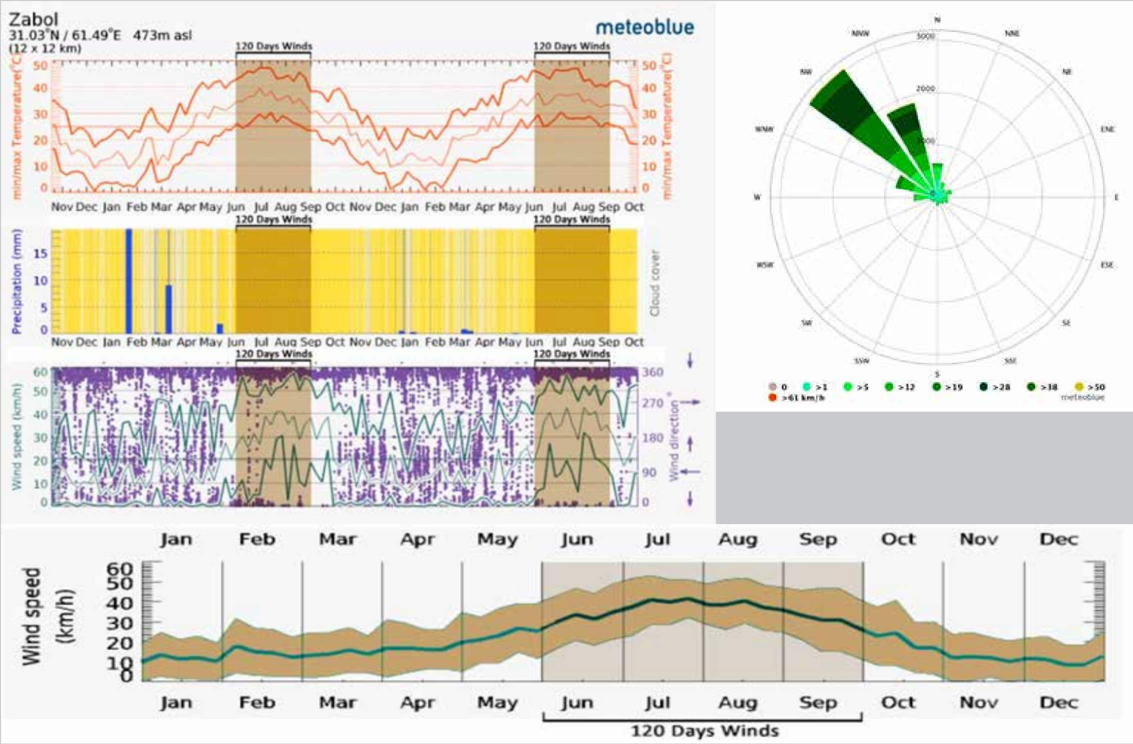


[Fig-38] Left: Al Kufa 35 km from Diwaniya (From: Ahmed Saker Paper); The Vernacular Architectural Ventilation Techniques in Hot and Dry Climates. Right: Iraq Wind-Box Position on the Map



[Fig-39] Iraqi Wind-Box with Two Openings

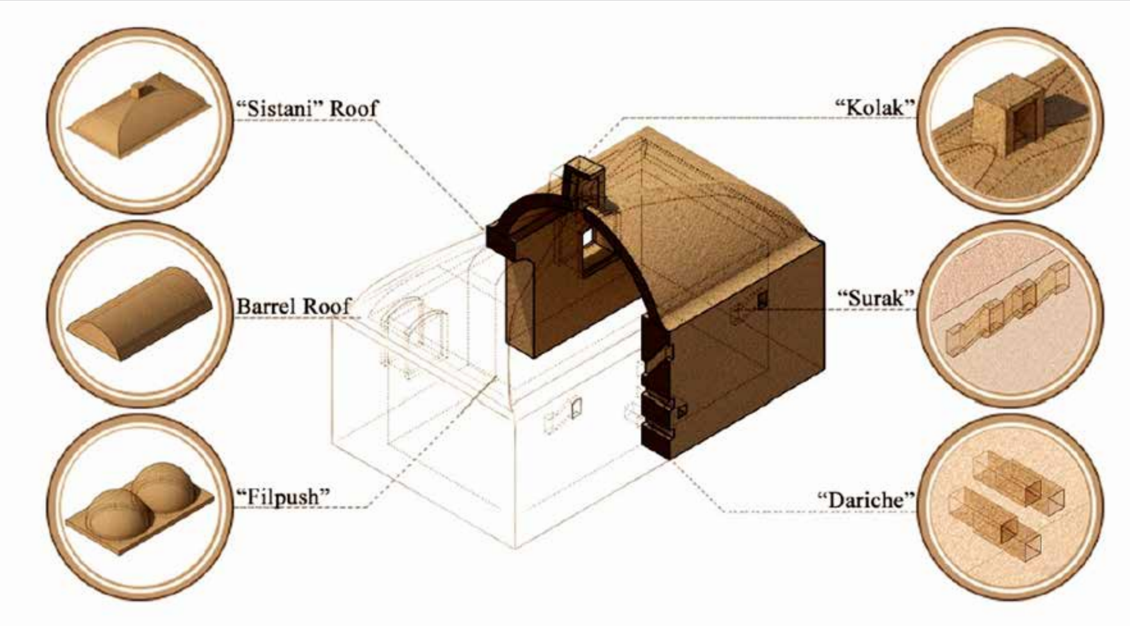
[Fig-40] Top-Left: Afghani Wind-Boxes. Top-Right: Position on the Map. Down: A Section from the Afghani Wind-Box



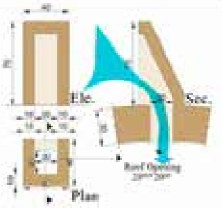
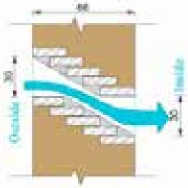
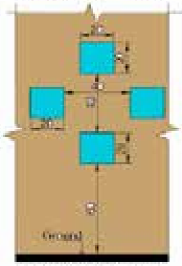
[Fig-41] Sistan Climate: Max., Min. and Average Temperature. Wind Direction and Speed (From [53])

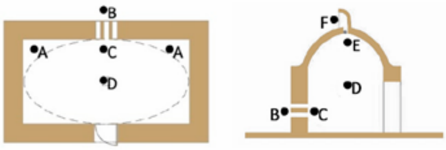
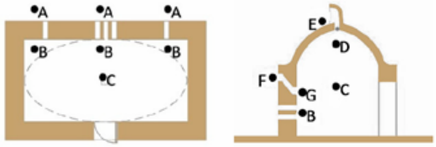
[Fig-42] Location of Sistan (From: [53])

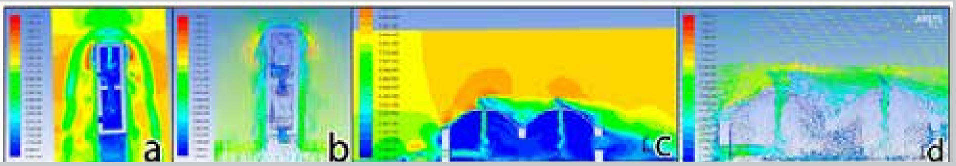
From the research of Abolfazl Heidari, Sadra Sahebzadeh, Zahra Dalvand, we can see all the information about the velocity of wind in two Sistan Wind-Boxes and modeled by CDF Fluent. [Fig-44] Here, we can see the wind has a different speed in different areas.
However, the main question is: considering that the opening of the Wind-Box is located in the southern part to receive the northern wind, how can the vernacular architecture of this area control pollution and the sand storms of 120-days? The answer is that when the storm starts, they add some other natural and vernacular architecture to this area: by using "thorns and thistles" to filter the area, sometimes also using grids on the wind entrance.



[Fig-43] Elements of Wind-Boxes of Eastern Iran (Wind-Box on Cupola) Elements (From: [53]

Ventilator openings	Kolak	 Kolak ventilator openings, native wind-catcher of Sistan	Native one-sided wind-catcher of Sistan, built in the middle of the roof, facing the region's prevalent wind (northwest to southeast) [48]. The curve form of the roof decreases the fraction and accelerates the wind towards the opening of the wind-catcher. This acceleration also causes the air pressure at the top of the dome to fall down, and therefore, air enters the room faster [21,53].	 Kolak ventilator openings, construction method
	Surak	 Surak ventilator openings	Canals in the walls, which are usually built in groups of three, located in the northwest walls. Two lids of each canal in two different sides of the wall are located in slightly different heights causing the wind enter the room obliquely and leave its contamination (especially sand) inside the canal before entering the room [11,46].	 Surak ventilator openings, construction method
	Daricheh	 Daricheh ventilator openings	Darichehs are a group of canals built in the northwest walls. Two lids of each canal in two sides of the wall are located in the same height causing the wind to enter the room directly. Daricheh is located in the lower section of the wall near the ground creating the opportunity to make a stack of hay in front of it. The stack is sprayed by water and when the wind passes through it, gets cooled off and enters the room as a cool breeze [47,54,55].	 Daricheh ventilator openings, dimensions

Room Sample 1		Room Sample 2	
Measurement Points		Measurement Points	
 Plan	Section	 Plan	Section
Wind speed		Wind speed	
VA = 0 M/S	VD = 1.5 M/S–1.7 M/S	VA = 3.5 M/S–9 M/S	VE = 7 M/S–8 M/S
VB = 3.5 M/S–9 M/S	VE = 8 M/S–13 M/S	VB = 5 M/S–14 M/S	VF = 8 M/S–9 M/S
VC = 5 M/S–14 M/S	VF = 7 M/S–8 M/S	VC = 1.5 M/S–1.7 M/S VD = 8 M/S–13 M/S	VG = 14 M/S–15 M/S



[Fig-44] Velocity of Wind and Wind Behavior Modeling CFD (From: [53])

[Fig-45] Left: Sistan Storm Right: Filtering by Thorns (Form: S.Molai, S.Soleimani Baq-Natanz)

5.4.2.10.1.5 Wind-Boxes of Central-North Iran (Wind-Box on Cupola)

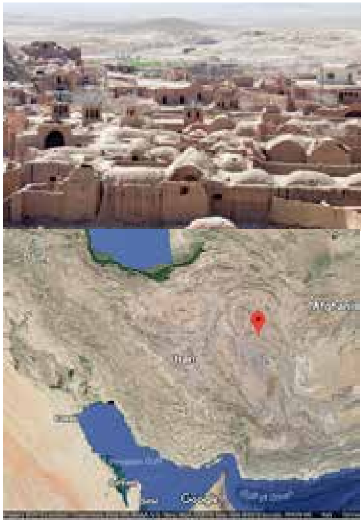
These Wind-Boxes are located in cities near Birjand, in the villages of Khor [Fig-46] and Dihook [Fig-47]. They have the same typology, where the Wind-Box is on top of the cupola, but they are different, as they are mostly bigger than the Wind-Boxes of Ghale Nuo village, and in the entrance of the opening, they have vertical parallel divisors.
The differences between Ghale-Nuo and Khor Wind-Catchers is that in Khor, they are larger and have buffers in the aperture.

[Fig-46] Khor Village

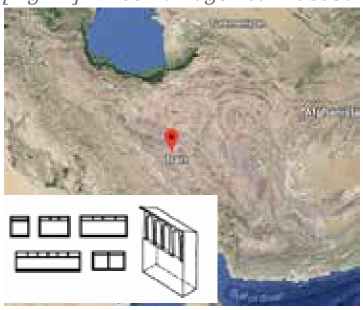
5.4.2.10.1.6 Wind-Boxes of Central Iran (Bad-Gir-e-Ardakani) (Capture-S Expulsion)

This kind of Wind-Box is famous as: Bad-Gir-Ardakani in some central cities near Yazd, where the wind direction is N-NE. We can find this typology in: Ardakan, Meybod, Aqda, Anarak, Tabas. etc. [Fig-48]
The plan and front face of one-opening Wind-Catchers are mostly rectangular [Fig-48] and are located at the end of “Tabestan-Neshin.” This term means summer-sit: semi-open traditional space located in the southern part of Iranian traditional houses. They do not receive direct sunlight and open into the interior yard, which usually is fresher due to the fountain and trees. This kind of Wind-Box is wider than the others, and has a lower height than Wind-Towers.

“We could usually find this kind of Wind-Catcher in the cities of Ardakan and Meibod. Their top opening is suitable for north winds and because they are typically short and are low cost to build, so there are more possibilities to build them in more places.” [60] In cities or villages with One-Opening Wind-Catcher like: Ardakan, Aghda, Tork-Abad, Ahmad-Abad, and Chupanan Meibod, the opening is mostly located on the northern side, and it is “closed on the south, east and west sides.” [61] [Fig-49] This is to block the warm and dusty wind that comes from the desert and receive the favorable wind that blows directly into the opening. In the case of water cisterns, if there is more than one Wind-Tower, the opening is not in the same direction. Cities: *Ardakan, Gonabad, Meibod, Bam, etc.*



[Fig-47] Dihook Village near TabasV



[Fig-48] Plan (by: Ali Mahyari) and Perspective of Iranian One-Opening Wind Catcher

[Fig-49] Top: View of Meybod. Bottom: The Widest Wind-Catcher of Iran with One Opening

[Fig-50] Soldier's Casern in Bam, Iran (Bam Castle)

[Fig-51] Position of Bam on the Map

5.4.2.10.1.7 Wind-Boxes of Iran with Three Openings

Location: Bam, Tabas
Bad-Girs with three openings are only seen in the city of Tabas, and in some small villages nearby, based on the research of (S. Roaf in 70-78). However, there are other ones, for example Sarbaz Khane of Arg-E-Bam, [Fig-50–51] where "soldiers casern in Bam castle" or Emamzade Hossein in Tabas "mausoleum of Emamzade Hossein" or in Sirjan near Kerman and Hossein Abad village near Yazd. [62] *"Wind catchers with three openings are closed on the west or south side"* [63] due to unsuitable and dusty wind blown from the closed side.
Iranian central Wind-Boxes could have better efficiency when there is a complex collaboration with other architectural passive elements like fountains, underground floors and cupolas.
The Passive Cooling Strategies of Wind-Boxes:

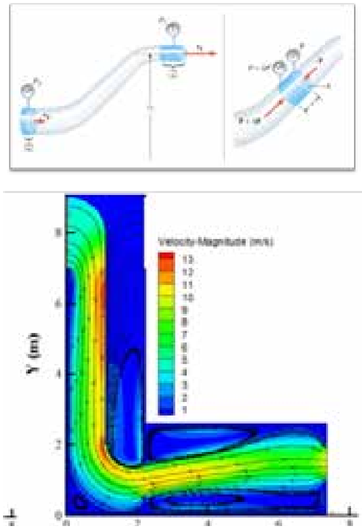
- Capturing the favorable wind where the wind constantly has one definite direction or in the same axis, but in two opposite directions.
- Expulsion of interior warm air when stormy (sand hurricane) warm wind blows from the opposite side of the opening.
- Increasing wind speed in the entrance of the opening that was built on top of the cupola.
- When there is no wind flow, the cupola could better lead the interior warm air towards the outside because warm area-ways move to higher levels and sphere forms have less friction than cubic ones.
- In the case of Cupola Wind-Boxes, the top air that enters in the room (through the ceiling) has a lower diameter, thus increases the wind speed based on the Bernoulli rule.
- In Cupola Wind-Boxes, the form has better cooling performance by night radiation to the sky.
- In the case of the Ardakani Bad-Girs (Iranian Central Wind-Boxes), they could have better performance in combination with evaporation from the fountain and vegetation, and connection with the underground floor "Sardab" could help to make the air flows cooler than simple ones. Also, this kind of Wind-Box could be combined with a cupola and could expulse the warm air out and increase the negative pressure, in other words, capturing more fresh air from outside and increasing wind velocity.

5.4.2.10.2 Wind-Towers

Wind-Towers or Bad-Gir are like towers that come up from vernacular buildings in ancient cities. They are much taller than Wind-Boxes and their measurements are generally much bigger too.

The Wind-Tower is: *"a tower designed and mounted on the roof of a building to "catch" the wind at higher elevations and direct it into the inner environment of a building."* [64]

"Hundreds of wind-catchers and courtyard houses still exist in the old quarters of cities such as Yazd and have been significant sources for research. This form of housing can be used in contemporary architecture as a basis for new development." [65]
Wind-Tower channels are divided into small parts by the interior buffer. When wind flows from one side, after contact with the head of the Wind-Tower (where the opening is located), it creates a positive pressure on that side, and then air flows down the channel and according to the Bernoulli Rules, passes through the tight duct and the wind speed increases when it comes down. [Fig-52]



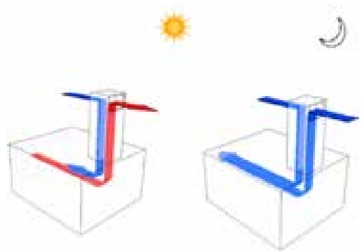
[Fig-52] Left: Bernoulli Effect on Wind-Tower Right: CFD Model Confirms This Theory

Wind-Towers Classification:

- Wind-Towers of Pakistan
- Wind-Towers of central Iran with two openings
- Wind-Towers of central Iran with four openings
- Wind-Towers of central Iran with six or eight openings
- Special Wind-Towers of central Iran
- Wind -Towers with Pipe form
- Two story Wind-Towers with opening
- Twin Wind-Towers

How Wind-Towers Work:

- A. **In the morning:** the mass of the Wind-Tower is cold because of night radiation to the sky and also cool night ventilation. Then low temperature is accumulated in the mass and interior buffers. Then, once outside, wind enters into the channel and loses some temperature because of convection with the cooler mass.

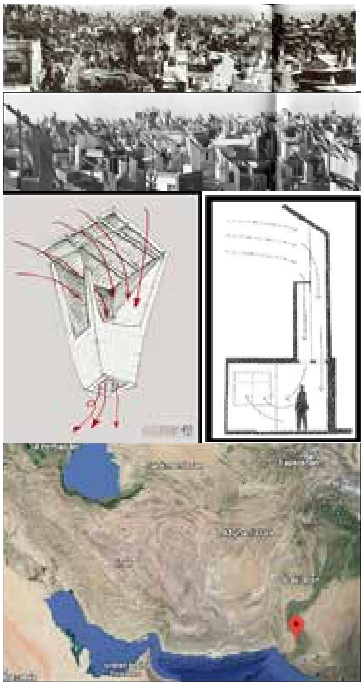


[Fig-53] General behavior Daytime and Nighttime Wind-Tower Behavior

- B. **At noon and in the afternoon:** the mass of the Wind-Tower becomes warm from sun radiation and convection with the outside warm airflow. Then when the air comes down, it does not lose heat and it is almost the same temperature as outside. However, in the Iwan, where there is no direct sun radiation in the shade, the air flow increases body evaporation and helps it to arrive to a thermal comfort zone.

- C. **At night**: at the beginning of the night, the Wind-Tower is so warm and it begins to transfer out the heat from its mass. It also works as a chimney in the buffers that are located on the opposite side of where the wind flows. In this area, there is an increased expulsion effect and it helps to absorb the cooler air from the courtyard fountain.

5.4.2.10.2.1 Pakistan Wind-Towers (Wind Scoops)



[Fig-54] Top: Skyline of Hyderabad Many Years Ago. Middle: Perspective and Section from Wind-Tower. Bottom: Position on the Map

Many visitors and travelers had written about the Pakistani Wind-Towers, but unfortunately today, there is no trace of them left from all the beautiful skylines of Wind-Towers of Hydarabad. They were mostly replaced by electric air-conditioning.

"These simple wind scoops on roofs completely dominated the city's skyline, rising above the houses like an endless sea of sails. A technique this widespread had to be effective – and it was a completely passive technique, requiring no electricity. Compared to *Iranian* wind-catchers, *which can work in many different ways depending on the design, use and weather, the Hyderabad wind-catchers are relatively simple. The wind-catcher essentially consists of a chimney-like opening, with a scoop on top that directs the wind inside the house.* [Fig-54] *These scoops are directed towards the southwest, because Hyderabad has a dominant and fairly constant wind from the southwest.*

The wind-catcher has a cover that can be opened and closed according to need. The wind-catchers were traditionally kept open during the night in the summer and during the day in the winter. They would serve only one or sometimes two rooms, and one house could have several wind-catchers." [66]

There is some kind of grid in the entrace of the room to block animal entrance inside the home. [Fig-55-56]

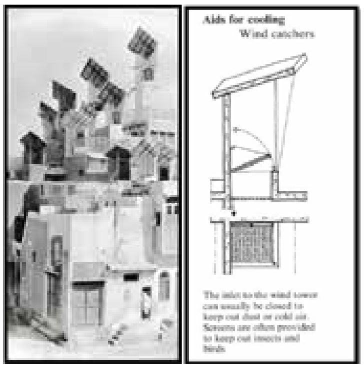
"The plan of Pakistani Wind-Towers is square shaped and their di-

mension is 1m X 1m. Their roof has an angle of 45 degrees over the duct. Every house in the old quarter of the city of Hydarabad, in the Sind province of Pakistan, characteristically had a wind scoop above its roof. "There is still a forest of wind scoops on the houses of the traditional quarters of the city." [67] [68]

Wind scoops have square tower heads, surrounded by two vertical plates, rising above the roof, roofed with 45-degree inclined planes, facing diagonally toward prevailing breezes, coming from the south-west. The plate is made of timber and plaster. In modern examples, they are made of corrugated metal sheeting supported on a timber frame with masonry walls. [69]

Average dimensions of the wind scoops are roughly 100 x 100 cm in cross-sectional size and 500 cm in height. They are surmounted atop a "windroom" from which air is introduced to the living space and may be separated by trapdoors. [70]

Another difference of Pakistani Wind-Towers is that they work like two-opening Wind-Towers, because they are closed on the two other sides. A 45-degree inclinment could help to push the wind into the duct. The end of the opening is tighter and based on Bernoulli principles. It increases the wind speed when it comes down to the main duct. Their main structure is thinner than the Persian ones so it works soley based on wind circulation



[Fig-55] Left: Hyderabad Pakistan Wind-Towers. Right: Open or Closed from the Roof.

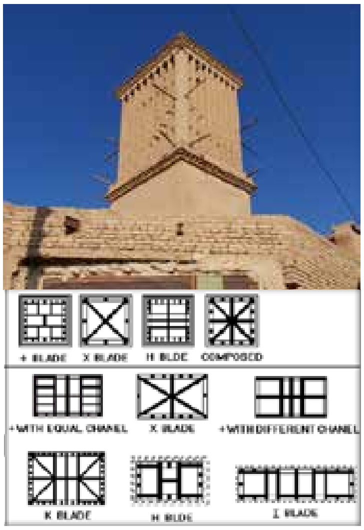
[Fig-56] Hyderabad, Pakistan Wind-Towers view from Inside

5.4.2.10.2.2 Wind-Tower of Central Iran with Two Openings (Capture/Expulsion)

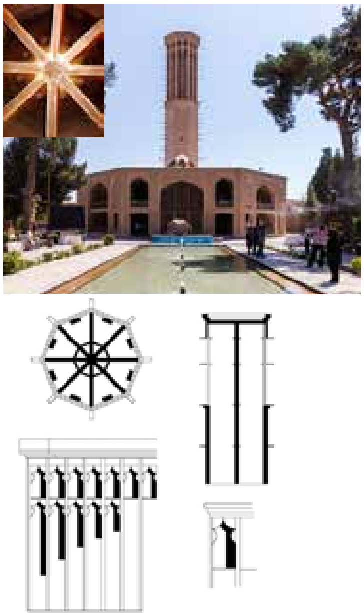
Location: Yazd, Rafsanjan

Having two openings is one of the central types of Wind-Towers, but it is not the typical Wind-Tower of Yazd. One of the openings works as a capture and the other side, at the same time, works as an expulsion. [Fig-57]

[Fig-57]



[Fig-58] Top:View of Wind-Tower with 4 openings. Bottom: Different typology in Plan X, K, H...



[Fig-59] Dolat-abad Garden Wind-Tower whit 8 openings- Left: View from Below the Wind-Tower

5.4.2.10.2.3 Wind-Tower of Iran with Fours Openings

Location:Yazd,Kashan,Kerman,Sirjan,Aqda,Tehran,Tabas,Rafsanjan *"This kind of Bad-Gir is usually more complex, larger and higher than others"* [71] and in hot and dry climates, it can receive any possibility of wind in any direction. According to M. Bahadori Nejad's research, in his 56 case studies in Yazd, 93% of Wind-Towers have four openings. [72] They are higher, as they are suitable for wind that moves in higher levels over the ground. For four opening Bad-Girs could have rectangular or square plans for their main duct, but their interior divisors could have panels with forms like X or H or K or a mix of them. In case of orthogonal or hexagonal prisms or cylinders, they could receive wind in any direction. They are usually very tall and there are fewer than the others. Their main duct is orthogonal or hexagonal or cylinder but their interior divisors are diagonal.

5.4.2.10.2.4 Wind-Towers of Central Iran with Six or Eight Openings

The six and eight-sided Wind-Catchers (with hexagonal and octagonal cross-sections) have rarely been seen in residential buildings. They were instead, frequently constructed over the water cisterns, particularly in hot and arid regions of Iran. [73] They could be more functional than the four opening Wind-Towers due to the possibility or receiving wind from six or more different directions, and they are usually taller than four opening ones (i.e. Dolat-abad Garden).

5.4.2.10.2.5 Special Wind-Towers of Central Iran

5.4.2.10.2.5.1 Pipes from Wind-Towers

There is just one example Pipes Wind-Tower in Iran and is located in Sirjan .it can receive suitable wind from different directions.[Fig-60]

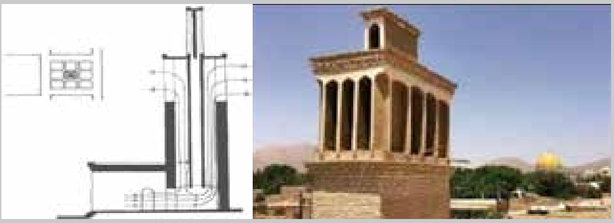
5.4.2.10.2.5.2 Two Story Wind -Towers with Opening [Fig-61-64]

There are different kinds of the Wind-Catchers that have unusual particular shapes and they are very rare. For example, double wind catchers whose central parts of interior panels rise more than their main body, and become like two level wind-catchers. This kind of wind catcher has the possibility to receive wind in both its higher and lower heights and *"it was used to getting fresh air in its higher level."* [74]

[Fig-60] Seid Ali Asghar Razavi House in Sirjan, Iran. Built around 100 Years Ago. Pipes Form a Unique Kind of Wind Catcher. Just this One Example Exists.

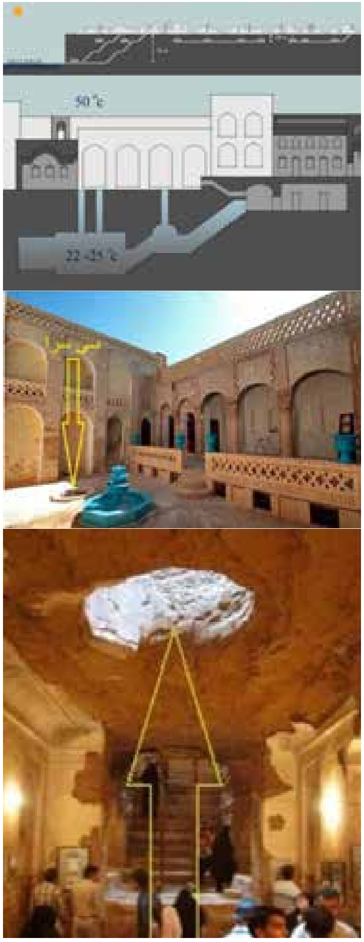
[Fig-62] Baq-Namir inTaft-Wind-Tower with two different levels of opening and two different directions

[Fig-63] Double Cylinder Wind-Catcher 10m Height in Chehel Sotoon, Sarhang Abad Village, Zavareh, Iran



[Fig-64] Right:Karvansara Rashti ha -Aqda
Right: Wind-Catcher of Nosrat Abad Village Mosque, Iran

[Fig-61] Aghazadeh House in Abarkooh, Iran. Double Wind-Catcher in the left of Iwan and cupola



[Fig-65] Top: Ghaleh-Salasal, in Shushtar. Top Left: Map Position. Bottom Left: View from Courtyard. Bottom Right: View from Inside

5.4.2.11 The Showdan

The particular position of the compact city of Shushtar is 30 meters higher than Dezz River levels. This helped to invent the Showdan and this type of the architecture. In the historical center of Shushtar, the allies are narrow with high walls on two sides, which creates more shadow and gives more speed to air movement.
The underground floor under the courtyard is much deeper than the underground floor elsewhere. The depth of the Showdan could be10 to 20 meters underground. It is one of the coolest places in the home during the hot and dry climates of Shushtar in Western Iran (near Iraq). The Showdan has different rooms with different levels of depth, and these places are connected together with long stairs. The temperature in the hot climate of Shushtar is around 45 – 50°C, but inside the Showdan, the temperature is constantly at 24 °C in summer and winter. These deep and cool places are connected by some channels (ducts) to the courtyard to create air circulation. It is interesting to note that the neighbors who lived close by had connections to one another through their underground Showdans.
The difference between the courtyards of Central Iran and Shushtar courtyards is that in Shushtar courtyards, there is no vegetation because it could damage the Showdan in the long-term. [Fig-65]

5.4.3 Egyptian Vernacular Architecture Strategies for Passive Cooling Architecturev

5.4.3.1 Central Courtyard

Just like many other ancient countries, the central courtyard is the main typology of traditional architecture in Egypt. "*The current work classifies the traditional passive techniques based "on Fathy's classification and Givoni's affecting factors on thermal performance of buildings.*

The main Egyptian traditional architectural elements are:

- *1. **Sahn /hosh:** the courtyard*
- *2. **Malkaf:** the wind catcher*
- *3. **Nafora:** the Fountain*
- *4. **Shesh:** Venetian blinds*
- *5. **Taktaboosh:** covered outdoor seating area at ground level*

- *6. **Mushrabiya:** open wooded lattice screens*
- *7. **Rasha/taka:** a small opening at an upper level of a wall*
- *8. **Salsabil:** a water-fed cooling plate*
- *9. **Shuksheika**: the vented or fenestrated lantern over the main hall*

[Fig-66]

People used to open their houses onto a private internal open space that visually and acoustically separated from the outside called Sahn "The courtyard" (Afify, 2002). The courtyard helps in maintaining cooled indoor temperatures. With some modifications to the courtyard, such as using water and vegetation in its landscape, the benefits can be maximized and particularly the benefits of the thermal performance.

There are three factors that affect the capability of the courtyard:

*The **deepness** of the form (R1), which is the ratio between the courtyard's perimeters to the height. (R1 should not be less than 3)*

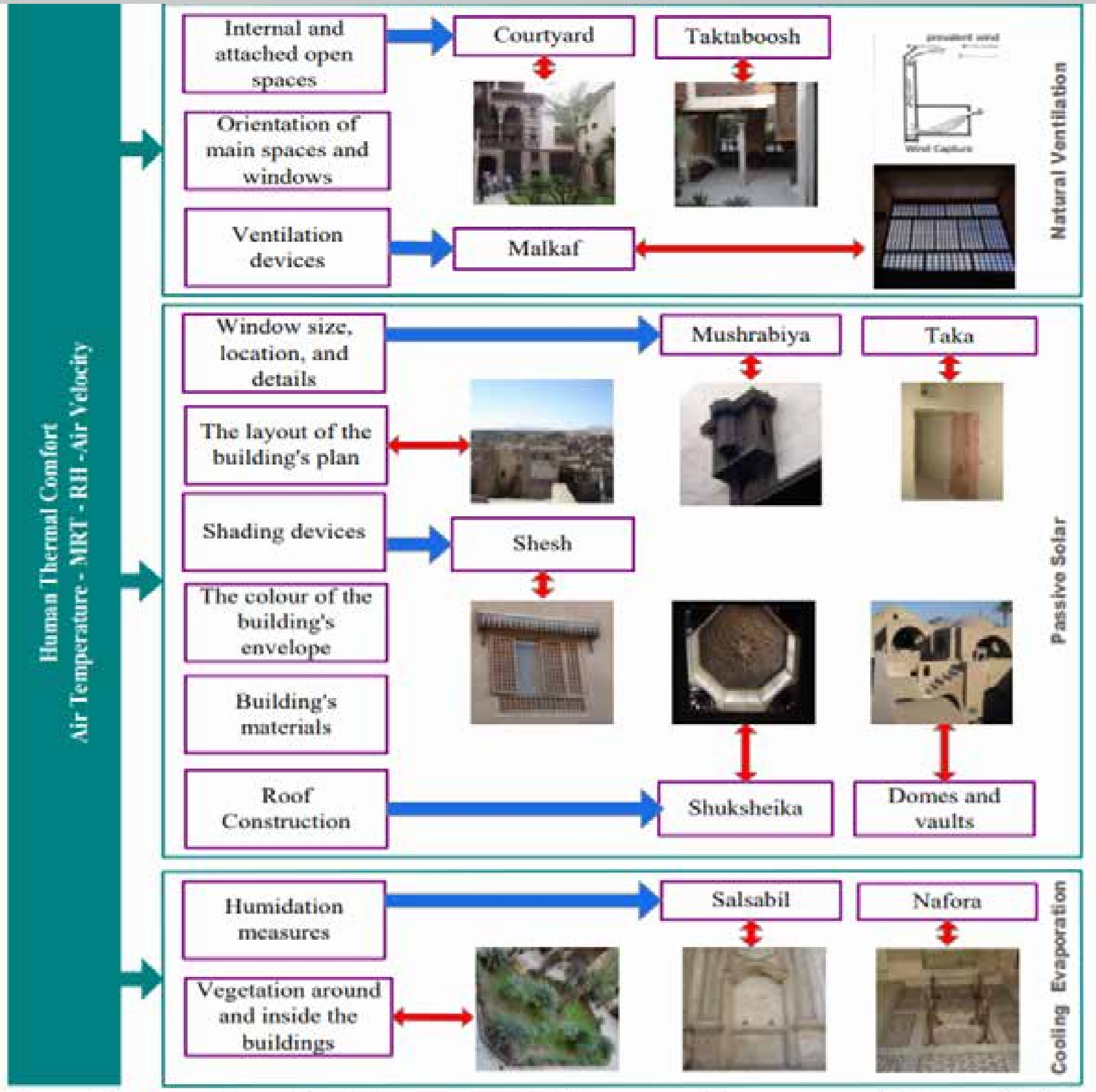
*The **elongation** of the plan, which is the ratio between the length to the width of the courtyard. The rectangular shape of the courtyard's plane is better than the square one. He also recommended that the ratio between the length, width and the height must be not less than 1:2:1.4.*

*The **openness** to the sky, which is the ratio between the area of the top to the area of the bottom of the courtyard.*

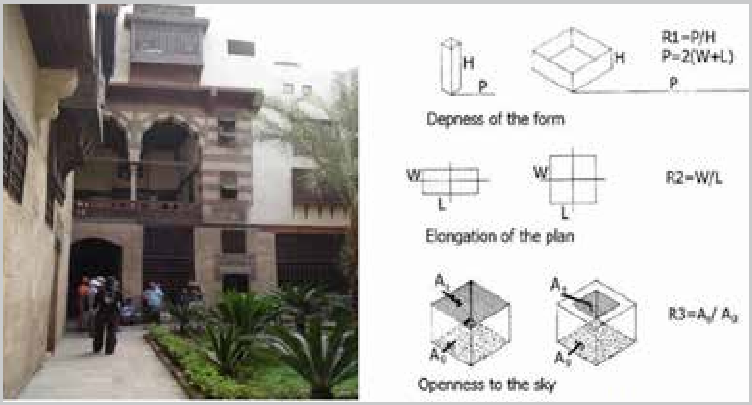
He added that the best orientation for the courtyard is by orienting the long side to the east west. A recent study (BMT Fluid Mechanics, 2007) concerned by the effects of surface openings on the air flow caused by wind in courtyard buildings, suggested that openings should be in the upwind and downwind surfaces to achieve the maximum air velocity. It added that the larger the upwind surface openings, the more the velocity increases significantly." [75] [Fig-67]

The courtyard (Hayat-e–Markazi) in a hot-dry and hot-humid climate is usually the heart of the dwelling spatially, socially, and environmentally. Although, the size of the land, to some extent, is influential, the average sizes of the courtyards are generally determined according to the latitude. They are narrow enough to maintain a shaded area during the heat of the day in summer, but wide enough to receive solar radiation in winter. A courtyard can provide security, privacy, and a comfortable place within the house. The courtyard usually planted with trees, flowers and shrubs, not only provides a comfortable condition and beautiful setting, but also supplies some shade and increases the relative humidity of the courtyard space. "Even without modern, mechanical heating or cooling systems, the courtyard house provides

v



[Fig-66] The integration between the traditional passive measures/factors affecting thermal performance buildings/ factors affective human thermal comfort



[Fig-67] Left: Courtyard of Al-Souhimi house- The geometric dimension of the courtyard [76]

a comfortable living environment through seasonal usage of sections of the structure. The thermal performance of courtyards has been studied by many researchers." [77] [78] [79]
The thermal capacity of air in the courtyard is very low and the temperature of this air follows very closely the temperature of the surrounding surface at night. The mass of the walls and floor of the courtyard is cooled by outgoing long wave radiation, and therefore, the surface of the courtyard floor and walls will remain cool by the following morning. In this way, the mass of the walls and floor of the courtyard (and not the air deposited in the courtyard), serves as a reservoir of coolness, if it is not too large and well shaded. For this reason, one may feel cool in two ways, firstly, the courtyard air is cooled in contact with the surrounding surfaces, and secondly, by losing heat through the surrounding surfaces by radiation, which is known as radiant cooling.

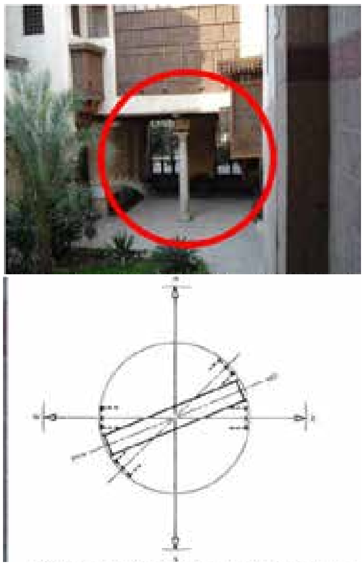


Fig-68]Top: The Thakhtabush in Al Souhimi House , Cairo - Right: The optiomal orientation with regard to the sun the prevailin winds (Fathy,1986)

5.4.3.2 The Takhtabush or Takht-Tabus

Hot air rises from the floor and draws the cool air out from the courtyard through the Takhtabush. This creates a cool draft between the two spaces. [80]
The Takhtabush "A covered outdoor seating area at ground level" was introduced in the Mamluk period to the traditional courtyard in Egypt in the 12th Century. [81] *It is located between the shaded courtyard and the backyard, and opening completely onto the courtyard through a Mashrabia onto the backyard, which ensures a steady flow of air by convection (Fathy, 1986). Several studies investigated the thermal performance of the courtyard and few of them highlighted the importance of the Takhtabush. No one investigated how far the Takhtabush can affect the thermal performance of the courtyard.* [82] *To ensure the air flow, a covered area at the ground level (the Takhtabush) was introduced to the traditional house. It is located between the courtyard and the back garden, opening completely onto the courtyard and through a Mashrabiya onto the back garden which ensures a steady flow of air by convection*. Since the back garden is *larger and thus less shaded than the courtyard, air heats up more than in the courtyard. The heated air rising in the back garden draws cool air from the courtyard through the Takhtabush, creating a steady cool breeze.* [83] [Fig-68,69] *The concept of Takhtabush was introduced especially in North African countries like Egypt. The Takhtabush is a type of loggia. It is a covered outdoor seating area at*

[Fig-69] Takhtabush in Al Souhimi House

ground level that separates the courtyard from the back garden. This disposition creates another case of ventilation by convection, since the back garden is typically less shaded than the courtyard. [84]

5.4.3.3 The Mashrabiya

[Fig-70] Top: Exterior View of a Mashrabiya Hassan Rashed, Egypt (Steet,1988) - Bottom: Internal View of a Mashrabiya in Al-Souhimi House, Cairo

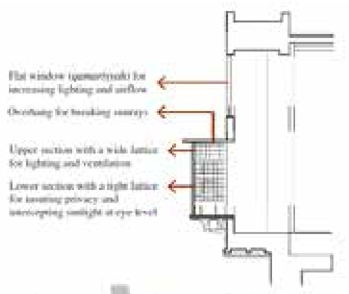
The name "Mashrabiya" is derived from the Arabic word "drink" and was originally a "drinking place" where jars of water were placed to be cooled by the evaporation effect when air moved through its space. It is essentially a wooden lattice window with conspicuous geometric patterns composed of very small wooden balusters around sections.

According to Fathy (Fathy, 1986), the Mashrabiya has many different functions among which: controlling the passage of light, controlling air flow, reducing the temperature of the air current, increasing the humidity of the air current and assuring a great amount of privacy. The sizes of the interstices and the balusters of the Mashrabiya are adjusted to intercept direct solar radiation using a lattice with small interstices and to allow air flow using a lattice with large interstices (Fathy, 1986). Therefore, a large interstice pattern is used in the upper part of the Mashrabiya to allow the air flow while small interstices are used in the lower part of the Mashrabiya to prevent direct sunrays. [85] [86] [Fig-70]

According to architect Hassan Fathy, the southern sunlight entering a room has two components: the direct high-intensity sunlight and the lower intensity reflected glare. Mashrabiya's interstices both intercept the direct solar radiation and soften the uncomfortable glare. In addition, considering that the Mashrabiya is made of out wood, it helps regulate the humidity inside the space. It is known that wood absorbs, retains and releases water. When air passes through the interstices of the porous wooden Mashrabiya, it vaporizes some of the moisture gathered in the wood and carries it towards the interior. [87]

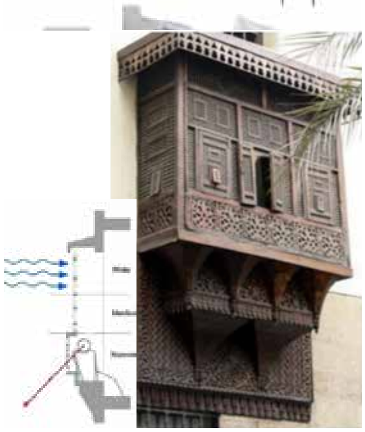
There are some unique features found in traditional Cairene courtyard houses, such as the Mashrabiya, Shokhshekha, and Malqaf. Openings of the houses are covered by the Mashrabiya's narrow openings breaking the sunrays and allowing airflow into the building. They provide privacy to the household by letting the family see the street while preventing people on the street or the neighbors from seeing inside their house. [88] [Fig-71]

5.4.3.4 Shokhshekha



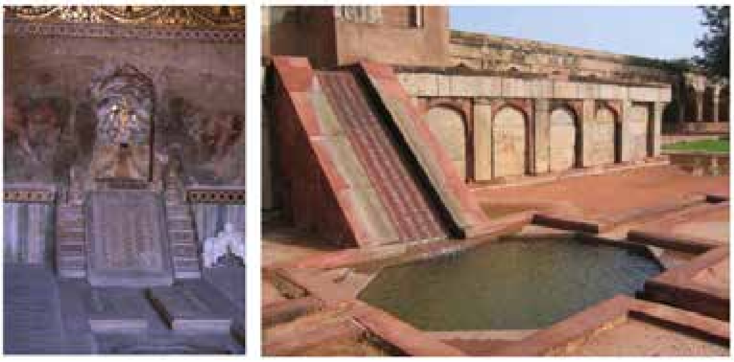
The Shokhshekha is a flat skylight roof made of wood in the middle of a space, with side adjustable windows, which can be opened to vent warm air and provide natural lighting.
Its function is like a normal cupola with an opening, but because of the wooden material used, it does not work as a thermal mass.
[Fig-72]

5.4.3.5 Salsabil



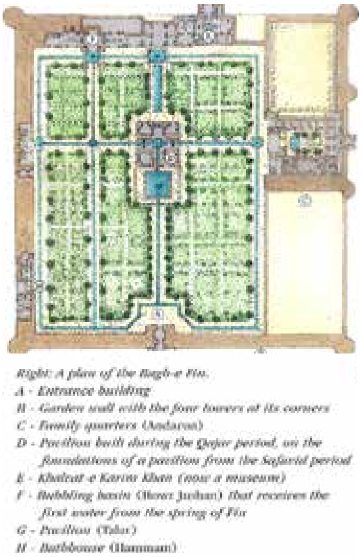
[Fig-71] Mashrabia Privet Vision to Outside

In places, where there was not enough pressure to permit water to spout out of the fountainhead, architects replaced the fountain with the Salsabil. [89] *The Salsabil is a marble plate placed at an angle to allow the water to drop over the surface, thus facilitating evaporation and increasing the humidity of the surrounding air. The water then flows into a marble channel until it reaches the fountain in the middle of the courtyard.* [90] [Fig-73]
“Salsabil” means the pond of paradise in Islamic tradition and is a device used to facilitate evaporative cooling. It consists of a water spout at the back of a niche; an inclined marble slab on which water flows, and a thin water channel that connects to a pool in the center of a courtyard. Salsabil is a transposition of the fountain and the wave pattern carving represents wind and water.



[Fig-73] Left: Salsabil fountain La Zisa Place ,Palermo, Right: Salsabil at Mughal Emperor Humayun'sTomb Dehli India

[Fig-72] Skokhsheikha at El Suhaimy House, Cairo, Egypt. Source: Wahid Khalil, www.adigicam.com



[Fig-74] Persian Garden with Rectangular Divisions, Fountain in the Middle of the Roads and the Kushk Building in the Center, in Kerman, Iran. Figure from (Khansari et al. 1998)

[Fig-75] Top:Kushk and founatin with special Bad-Gir in Baq Namir ,Taft .Bottom: Fountain In Baq(Garden)Shazdeh Mahan,Kerma

5.4.4 Kushk (Single Building in Iranian Garden)

5.4.4.1 Iranian Garden “Pardis”

Iranian garden ”Pardis” means “paradise.” The geometric structure can be considered as one of the most prominent features in Persian gardens. Two main horizontal and vertical roads inside the plan cross each other and create a symmetry. The Kooshk is located at the center of this cross. [Fig-74]

5.4.4.2 Kooshk (Single Building in Iranian Garden)

In Iran, like any part of the world, rich merchants and powerful people had big dreams, one of which was to create their personal garden, also know as their “Paradise.” Kooshk is the name for the main large building in the center of the Persian garden. It usually has a symmetric plan and contains an interior geometric fountain. [Fig-75]

5.4.4.3 Fountain

Typically, gardens contain a very long fountain that starts from the beginning of the entrance on the axe of the symmetry. On the two sides of the long fountain, rows of trees were planted to act like two walls that direct the air movement over the long fountain. By passing the air over the long fountain, the air temperature continues to drop until it arrives to the Kooshk. [Fig-75]

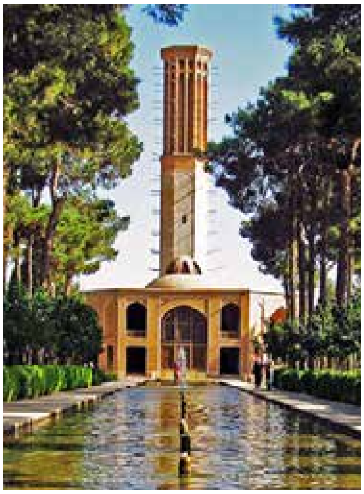
5.4.4.4 Wind-Tower

The Wind-Tower is an additional part of the Kooshk, located in certain central hot climate cities in Iran, such as Yazd and Taft. Based on the traditional architecture of these areas, their Wind-Towers are slightly different – they are much bigger than normal ones. For example, Dolat – Abad, the highest Wind-Tower of Iran has a height of more than 30 meters. The Wind-Tower typically has different functions, depending on the time of day.

- **In the morning:** it works as a wind capture tower. The body of the Wind-Tower becomes cold during the night and it guides wind in any direction into the internal part, passing the air through its body and becoming cooler than before. It then arrives down into the Kooshk.

- **In the afternoon:** the body of the Wind-Tower works as a thermal mass. Then the warm air inside its body moves to the top and stops the wind from coming down. This effect brings fresh air which passes over the long fountain into the Kooshk.

- **At night:** the massive body of the Wind-Tower radiates to the sky and loses the heat that was absorbed during the day. Therefore, at first, more effort is made by directing the air out of the building; but during the late evening and middle of the night, when its body has the same temperature as the outside, it works a capture Wind-Tower. [Fig-76]



[Fig-76] Iran's The Tallest Wind-Tower of Iran in Doalt Abad Garden Yazd.

5.5 Vernacular Urban Strategies for Passive Cooling Strategies In Hot-Dry High Relative-Humidity Climates (Persian Gulf)

The southern part of Iran, located just north of the Persian Gulf, is made of compact urban texture, narrow alleys, light colors and its houses usually have higher ceiling on their two or three floors. The courtyard is on the same level of the basement and because of the region's low water level, there are no basements in these areas. The rooms located on higher floors usually have windows one two sides, one facing the courtyard and the other facing the alley. This helps the wind flow movement.
The fountain does not have an important effect on cooling the air flow. Because of the high humidity, the air is already saturated with water molecules and it cannot lose any more energy to evaporate the water.

5.5.1 Color

Typically, the color of the walls inside the houses in this area are either white or light adobe. This helps the houses reflect the sun rays and thus absorb less radiative energy. The glass on their windows are usually made with different colors to filter the sun rays.

5.5.2 Path, Roads and Direction

In the Persian Gulf areas, the roads are narrow and they are usually directed towards the coastline to utilize the natural sea breeze. They have some deviation from the sun's direction in order to receive lower radiation and create more shade.

5.6 Vernacular Architecture Strategies for Passive Cooling in Hot Dry Low Relative Humidity Climates (Persian Gulf)

The main traditional strategies in this area are:
- Using sea-wind
- Producing more shade
- Central courtyard
- Wind-Tower
- Vegetation
- Higher ceilings

5.6.1 Wind-Towers in Hot and Dry Climates with High Humidity (Persian Gulf)

In Dasht-e-Khozestan, for example, which is located in southwestern Iran, high humidity climate is known as "Shargi." The vapor pressure is fairly steady, varying with the location and season from about 5 to 15 mm Hg. The relative humidity, therefore, fluctuates with the air temperature, ranging from below 20% in the afternoon to over 40% at night. [91] [92]
This type of Wind-Tower can be found in southern Iran and in Arabic countries around the Persian Gulf and Oman Sea. There are four openings on its top and its interior Shuffle is shaped like the letter "X." These are larger than the Wind-Towers of Central Iran.
Their main function is capturing sea/land-breeze during the day and night. They are large – as large as the width of the room below.
The classification of Gulf Wind-Towers is not so varied, but due to their diverse decorations, they could be divided into two categories:
- Iranian Gulf Wind-Tower
- Arabic Gulf Wind-Tower

5.6.1.3.1 Iranian Gulf Wind-Towers

"In Bandare Lengeh, Bandare Khamir, Bandare Laft, Bandare Kong, Gheshm Island, Minab, Bandar Siraf,.. There are several ports on the Persian Gulf coastline with many Wind-Catchers that easily push sea suitable airflow inside the buildings… Every building has a minimum

of two Wind-Catchers that are located in two different sides of the house. Their shape are all the same and they look very bulky … because of the wind blowing from sea to coastline, the breeze usually occurs in low levels, so they are not very tall. They have a square shape. Wind-Catchers with a rectangular form are very rare in this area. Big Wind-Catcher ducts sometimes have 9 m^2 areas and are divided with an X form interior divisor panel." [93] [Fig-77]

[Fig-77] Bandare Lengeh -Iran (LEngeh Port) Massive Wind-Towers for see-breeze

5.6.1.3.2 Arabic Gulf Wind-Tower

Wind-Tower shapes located in the Arabic countries of the southern part of the Persian Gulf are very similar to southern Iranian Wind-Towers, the reason being that they both have the same climate. For many years, southern Persian Gulf countries were a part of the large Persian (Iranian) territory, and because of the maritime commerce between the southern and northern parts of Persian Gulf, many people moved or immigrated from south to north or in vice-versa.

"Wind-Towers existed in Arabic countries and the islands in the southern parts of the Persian Gulf like Kuwait, Bahrain, Qatar, Emirates, and Oman. For example, in the suburbs of Dubai, we can find the Bastak quarter with many Wind-Towers, which were created in 1889 by some people who immigrated to Dubai from Bastak, a little village near Bandare Lengeh, Iran. The Wind-Towers of this area have flat roofs and their dimensions are 2.5 m X 2.5 m and they received wind from four directions because of the low height sea breeze." [94] [Fig-78,79,80]

[Fig-78] Isa Bin Ali House, Bahrain

[Fig-79] Bastakia Wind-Tower, Dubai

[Fig-80] Rafeek Manchayil vWind-Tower, Qatar

5.7 Conclusion

A. Human Thermal Comfort Condition:
There are various factors that could be effective on thermal comfort in each site (place).
For quantitative factors, we should analyze different data gathered, such as the level of relative-humidity, temperature level, and wind or air flow speed. For qualitative factors, we should control the level of dust and air pollution etc. but it is important to note that we should have information about all of this data in order to use them in the best way possible for bioclimatic passive architecture.

B. Traditional Bioclimatic Urban Strategies in Hot Climates:
Some of the ancient traditional urban strategies in hot climate countries could also be useful today. For example, building the main and secondary streets along the same direction of the local suitable winds, particularly in cases where the city is located near the sea, hills, or valleys. Otherwise, if the local wind brings more pollution and comes from warmer areas, it is better to have deviation against the hot or dusty wind. Also, covering the streets with fabrics to create more shade could be a considerable idea.
There are other ancient urban strategies that are not appropriate for the urbanism of today; for example, having narrow alleys, which block access to cars and emergency vehicles. Underground cities require more studies in order to see how much of it can be operative, but certainly on a lower scale, like an architectural scale, it could be useful.

C. The Vernacular Ancient Bioclimatic Architecture
The most important points regarding this architecture are that:
- The architecture of that period found innovative solutions to help people better cope with the high temperature climate issues they faced in daily life. Obtaining thermal comfort through the use of natural resources and architectural shapes is the main characteristic of the vernacular architecture of the Middle East. Examples include utilizing the lower temperature of basements,

producing more shade against the sun's high radiation, and evaporating and increasing air flow from cooler parts towards other spaces. Also, the use of other architectural elements, like the cupola, directs warm interior air towards the outside; and the use of Wind-Towers or Wind-Boxes, captures or pushes out the air flow.

- In their architecture, there are specific spaces and forms that coexist and cooperate together; for example, the Bad-Gir and Ivan, the Ivan and fountain and courtyard etc. If we found the logic behind their function, we can use these strategies for contemporary architecture.

- The architectural elements, to protect its users, utilize different components and methods according to wind direction, microclimate, position of the site and sun movements.

- In hot climates with high-humidity areas, usually near the sea, the underground water levels and humidity are not appropriate for using underground floors or basements. In those cases, where this is needed, we must rely on the use of new methodologies of insolation and construction. Additionally, the use of large fountains is not common because the humidity level is already very high, and more water will increase this humidity, which in turn, will worsen our comfort condition.

5.8 End Notes

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CHAPTER 6

Compound Analysis of Iranian Wind-Boxes & Wind-Towers in Cooperation with Other Architectural Elements (Case Studies A)

6.1 Objective

There is a lot of research regarding the "Bad-Gir," also known as the Iranian word for wind-catcher (perhaps better to say Iranian Wind-Boxes and Wind-Towers). Some of these papers had analyzed only the mechanical engineering aspects, while others had a formal vision and studied their size and form etc. There are also different CFD that analyze the effect of wind behavior in Wind-Towers in varying situations involving wind-speed, form, height, Shuffle, opening size etc. However, the vernacular passive cooling architecture is not formed from one single element. It is in fact, inspired from nature, having a complexity of elements that work in perfect harmony together. The vernacular passive cooling architecture of Iran, in collaboration and harmony with its different architectural elements, was able to resolve many of the problems that arise from living in the hot and dry climate of central Iran.

6.2 History of the Bad-Gir

[Fig-1] From the Book by Braun-Hogenberg entitled, Civitates Orbis Terrarum ("Cities of the World"), published in 1577 in Cologne, Germany.

[Fig-2] Shemran Gate, Tehran by Eugène Flandin

In this chapter, for the first time, a new methodology to analyze and study Wind-Towers and Wind-Boxes will be presented. It will be along the same lines of other effective elements in vernacular ancient passive cooling architecture.

We will continue to search for a constructive dialogue regarding the questions and hypotheses around the history and origins of natural ventilation systems in Iran.

There is no precise information available confirming when or where the first Bad-Girs were created. We can only find their roots in various literature, i.e. poems and travel books. The Bad-Gir is introduced in different names in Persian terminology; for example: Bâd-hanj, Bâd-ahang, Bâd-khan, Bâd-khor, ect.

History in Poem Books:

The first time the poet Rudaki Samarghandi used the word *"Bâd-hanj"* in his poem book was in 950 A.C.

However, the first time that the exact terminology of Bad-Gir was used was in the poem book of Masud Saad Salman in 1061 A.C.

In 1292 A.C., in Marco Polo's travel book, he wrote about when he arrived to Porto Hurmoz in Iran, located at the top of the Persian Gulf, and he precisely described*: "the weather is awfully hot but they built some kind of ventilation tools on top of their houses with the purpose of receiving wind from the outside to cool the inside of their homes with a wind catcher* ..." [1]

Below, can see one of the most antique pictures of the Port of Hurmoz Island located in southern Iran. This is an artistic impression of Hormuz Island painted by Alfonso de Albuquerque. In 1571, the Portuguese created a special Augustinian Congregatio of East India, based in Goa, India. De Albuquerque travelled to Hormuz in 1573. In this picture, we can clearly see the Bad-Girs. [Fig-1]

Other people who travelled to Iran and wrote about its architecture and culture, and drew many of its places during their journeys are Eugene Flandin and Pasca Coust, who left France for Iran in 1840. In the first picture, we can see a Bad-Gir with four openings on its top. This is located in a town near Tehran. In the second picture, we can find a large Wind-Tower in Bushehr. [Fig-2]

6.3 New Methodology of Study for Ancient Wind-Towers and Wind-Boxes of Iran

It is important to understand how architects in the past organized spaces and architecture elements to create the best passive comfort in these extremely hot climates without any use of electric cooling system.
In order to study Wind-Towers and Wind-Boxes, we need to explore the other architectural elements of Iranian ancient vernacular architecture.

[1] Yule, H. The Book of Ser Marco Polo, the Venetian Concerning the Kingdoms and Marvels of the East, pp.383. London: John Murray, 1903. warburg.sas.ac.uk/pdf/ndb90b2202522A.pdf

6.4 Effective Architectural Elements on Performance of Wind-Towers and Wind-Boxes

In the traditional central courtyard structures in Iran, there are some elements that can help Wind-Towers have a better performance and each one could be useful in different ways. Some of them make the area fresher by evaporation or convection. Others help to suck out the interior warm air and some others help to create more differences between the air that arrives and the air that goes out, while others control some other elements.

6.4.1 Evaporation Cooling

- Fountain in courtyard
- Fountain in Iwan
- Fountain in underground floor "Sardab"
- Vegetation and tree

6.4.2 Thermal Mass Cooling

- Mass of building
- Mass of Wind-Tower

6.4.3 Geo-Thermal Cool Mass

- Horizontal aperture under the Wind-Tower between Iwan and underground floor (Wooden Grid)
- Wind-Tower of underground floor

6.4.4 Multiplier of Air Flow

- Cupola
- Twin Wind-Tower

6.4.5 Air Flow Controller

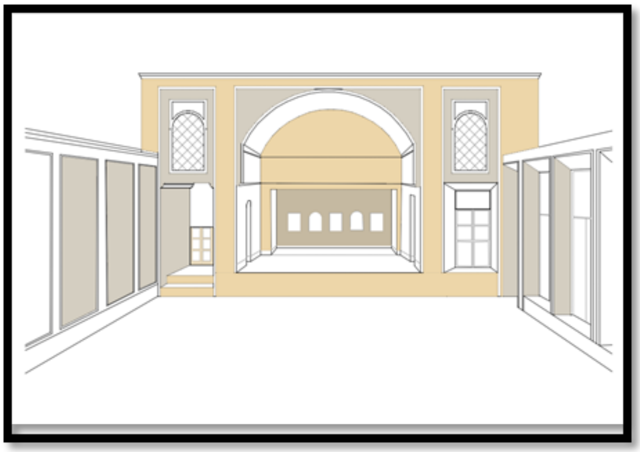
- "Orosi" Vertical aperture (vertical opening windows in Iwan to courtyard)
- Vertical aperture under the Wind-Tower in Iwan towards underground floor
- Adjustable aperture under the Wind-Tower duct

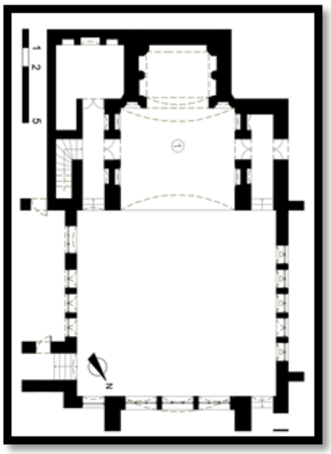
6.5 Hypothesis and Assumptions

It is completely true that: If every single architectural element in different size and form could have a different effect on power and efficiency in the strategy of passive cooling in buildings, we need to have a general map to analyze all the effects and elements to understand how they work together.
We assume that all houses in Iran have the same size Central-Courtyard and Iwan, and that the wind direction and its potential is equal. We also assume that each kind of Wind-Tower and Wind-Box has the same capacity of wind capturing.
We will also assume the same similarities for Gulf Wind-Towers, but it will not be discussed in these case studies.

6.5.1 Basic Model

The basic model includes a courtyard with Iwan based on the basic rules of the Iranian Central-Courtyard House. [Fig-4] We will continue by adding different architectural elements, trying to locate different classifications and all the while, find realistic examples of them in relation to these assumptions.



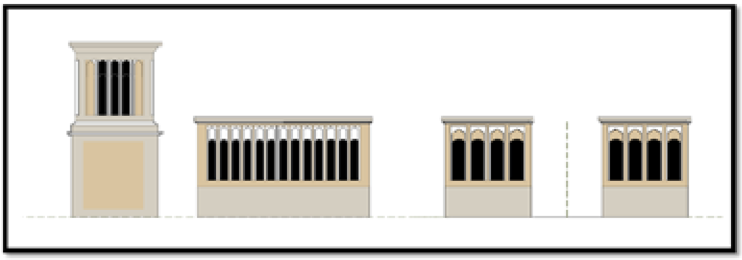


[Fig-4] Basic Model

6.5.2 Adding Elements (of Traditional Vernacular Passive Cooling Architecture)

6.5.2.1 Wind-Towers and Wind-Boxes

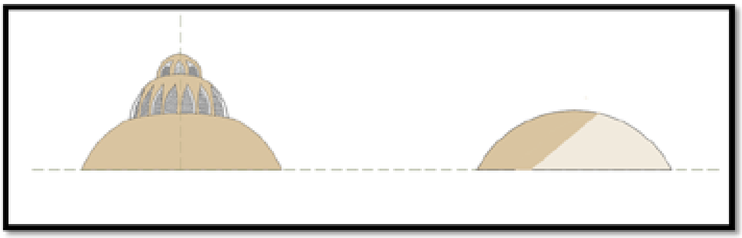
Vertical elements are located at the end of the top of the Iwan. They can capture or expel the air flow towards the inside or outside of buildings.
Different typologies of Wind-Boxes and Wind-Towers have been considered, including combination states, like Twin-Wind-Towers, and their positions compared to the symmetry axis. [Fig-5]



[Fig-5] Wind-Tower and Wind-Boxes

6.5.2.2 Cupola

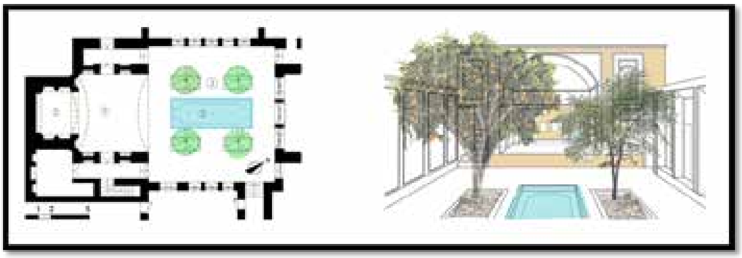
If the cupola has its opening on top, it will help to push out the warm air on top. It also has the best shape for night radiation to sky. It could increase negative pressure in the Iwan, which could help to give a better performance to the Bad-Girs. [Fig-6]



[Fig-6] Cupola

6.5.2.3 Fountain and Vegetation

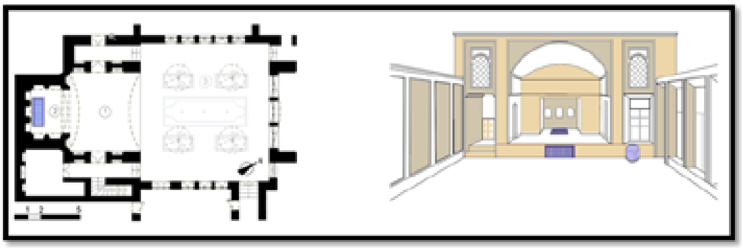
In the architecture of Persian houses, there is always a fountain. We can also find a little garden or trees that together, can help to decrease the temperature through evaporation. Trees also can absorb some of the sun radiation and reflect the rest by creating shade in the courtyard, which thereby reduces sun radiation. Trees also produce oxygen, which is good for the overall health of people around them. The fountain reflecting some part of the sun radiation, also works as a thermal mass by absorbing the heat in the air. [Fig-7]



[Fig-7] Fountain and Vegetation

6.5.2.4 Underground Floor (Basement)

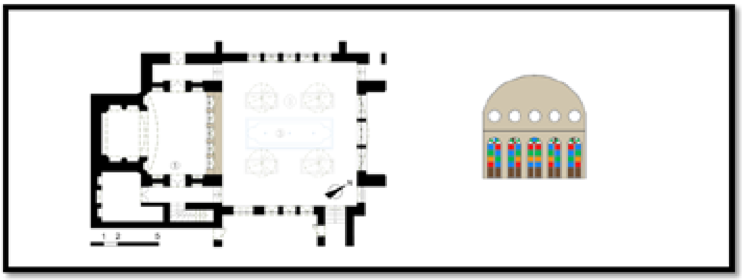
The underground floor, because of its position, receives the lowest level of sun radiation. Its five sides (floor plus four walls) is in contact with the lower level of the ground, whose temperature is constantly at 25 °C. [Fig-8]



[Fig-8] Underground Floor (Basement)

6.5.2.5 “Orosi” Vertical Aperture (Vertical Opening Windows in Iwan to Courtyard)

An “Orosi” is a wooden window divided in 3, 5, or for big Iwans, in 7 little windows, and mostly have colorful glasses. [Fig-9]



[Fig-9] Orosi” Vertical Aperture

6.5.2.6 Internal Fountain

The Internal Fountain is one of the most important cooling internal elements. Usually this element is present in traditional Mono-Buildings like “Kushk” in the center of the building. Also, by providing more humidity to the dry air and absorbing air heat, it could have a very positive effect on thermal comfort situations. These strategies have been used for many years in ancient Iranian and Arabic architecture. [Fig-10]

[Fig-10] Left:Dolat-Abad Garden Yazd, Iran
Right: Shotor-Galoo Place Mahan,Kerma, Iran

6.6 Case Studies

In the following case studies, we will try to show as much similarity as possible between the hypothesis and real example.
All of the pictures have been collected by:

- Personal visits to the cities of: Yazd, Kashan, Abarkoo, Meybod, Ardakan
- Archives of cultural heritage offices of each city
- Hours of research online
- Reading different books in many languages

Each table will present:

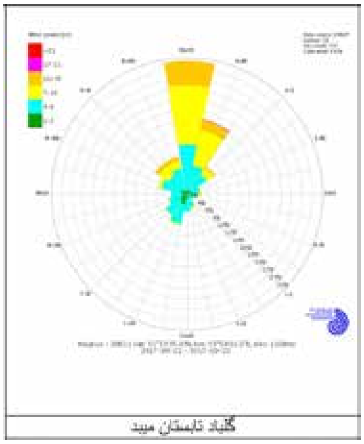
- Real example
- Perspective
- Section
- Different view and section from The Wind-Box or Wind-Towers
- List of Passive Strategies
- List of Passive Elements
- Number of Wind-Towers
- Other special characteristics

6.6.1 Typology A

The first category of the Iranian traditional central courtyard house with a Bad-Gir is dedicated to the building with Wind-Boxes with one opening on top.
As explained before, this typology has been used where the wind direction almost permanently remains in one direction or in two directions in the same axis but with 180 degree deviation.

- Capturing: will happen when the wind is blowing in the direction of the Wind-Boxes' opening holes.
- Expulsion: will happen when the wind blows from the back of the Wind-Boxes. In this way, the Wind-Boxes will work as expulsion Wind-Boxes.

Location: Ardakan, Meybod, Bam, Gonabad, Aqda, Tabas, Khusef, Esfahak, Anark, etc.

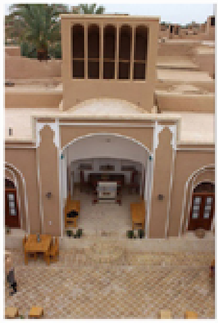


Meybod Wind direction Diag. in Summer 2017


[Fig-11] Ardakan Yazd One-Opening Wind-Boxes

6.6.1.1 Case N.1 Wind-Box – Razavi House, Ardakan, Iran

Real exmaple

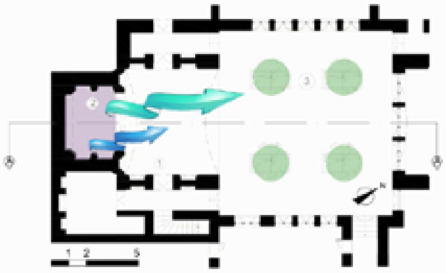


Wind-Box With One Opening

N.1

Perspective

Plan L: 0



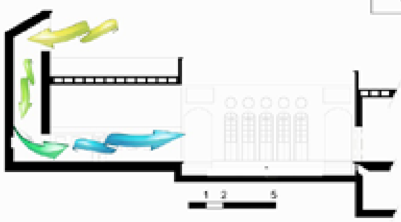
Passive cooling architecture strategies

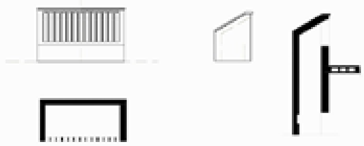
1. Passive cooling ventilation
2. Evaporation (Just by Trees)
3. Direct thermal mass cooling
4. Lower sun daytime radiation
5. Nighttime radiation to sky
6. Nighttime ventilation

Passive cooling architectural elements

1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	○
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

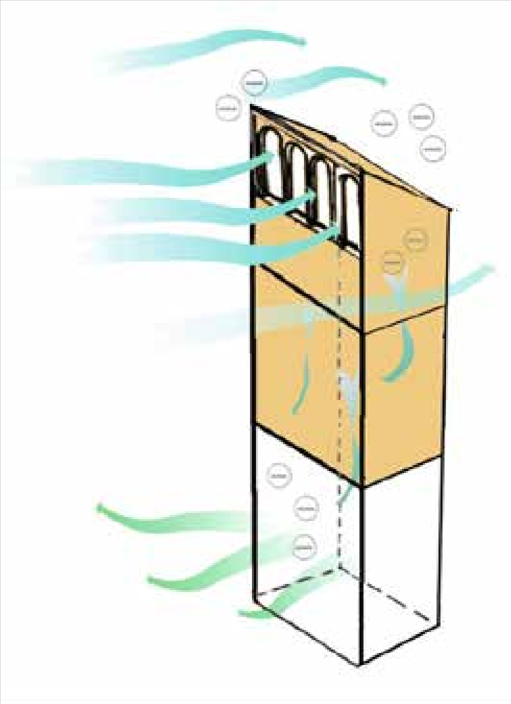
Section





Number of Wind-Boxes

1



خانه همایون نیلی :

این بنا دربیرونه محمود آباد ، میدان مادر کوچه روبروی بهزیستی قرار دارد. خانه همایون نیلی از نمونه های یک طرفه ساخت دوره قاجار است. ساختار ساده و یکسویه ی خانه و استقرار صفه ای در میان و دو اتاق در کنار آن و حتی راهروهای منتهی الیه ، پلان خانه های سیاق عصر صفوی راتداعی می کند . حتی محل راه پله ی پشت بام عیناً مانند جایگاه استقرار پلـه ی بـام در خانـه ی بلالی است . منتهی ضخیم وحجیم شدن لایه ی ساخت و ساز ، بادگیر مفصـل و ایجـاد حیاط های کوچک در پشت ، ویژگـی بـارزی اسـت کـه در بسیاری نمونـه هـای قاجاری بررسی شده به چشم می خورد . در محدوده ی پیرامون برج محمودآباد و اطراف میدان مادر، نمونه ای خاص از خانه های قاجاری به وفور وجود دارد . نمونه ای که شاید بتوان خانه – باغ نامید که تغییرات چندان زیادتری نسبت به خانه ی صفوی ندارد . خانه های سه طرف ساخت بـا عـرض کـم در محـدوده ی خانـه ی ملک مدنی شوروک وخانه – باغ های شبیه خانه- بـاغ هـای صـفوی ، منتهـی بـا اندک تغییر جزیی و عـرض زیـاد تـر زمـین در محـدوده ی بـرج کبـوتر خانـه ی محمودآباد بیشتر مواجه ایم . هر چند با ایـن داده نمـی تـوان بـه اسـتدلال گونـه شناسی دست یافت اما شاید در تحقیق این دوره ی خاص تـاریخی مسـأله محلـه ومحله بندی از دو دوره ی پیشین محکم تر مطرح شود .

این بنا که در جبهه شمالی خود دارای ساختار خشت و گلی مـی باشـد شامل صفه ایی با دهانه ۵/۵ متر در میان و اتاق هایی در دو بر صفه اسـت. جالـب است که سقف صفه همانند سایر بنا های همزمان با خط آسمانه سرتاسری این نما یکدست ویکسـان نشده وطاق صفه به حالت یک برجستگی طاقی شکل باشکوهی در میان ساختمان خودنمایی می کند . این ویژگی در تعـدادی از بناهـای دوره ی قاجاری دیده می شود و تا قبل از آن سابقه نداشته است . این مسئله در معمـاری بومی و روستایی بیشتر دیده می شود که یکی از دلایـل آن مـی توانـد وافتـادگی اجرای طاق ضربی و عدم اقدام به تصحیح و تنظیم پیشانی نما ی کار باشد .

جبهه شمالی خانه مبینی (پناه)

جبهه جنوبی (تسری)

[Fig-12] Homaion-Nili House Has in Courtyard (From: Cultural Heritage of Meybod)

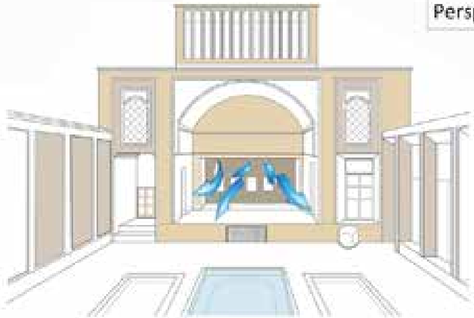
6.6.1.2 Case N.2 Wind-Box – Afzali House, Ardakan, Iran

Real exmaple

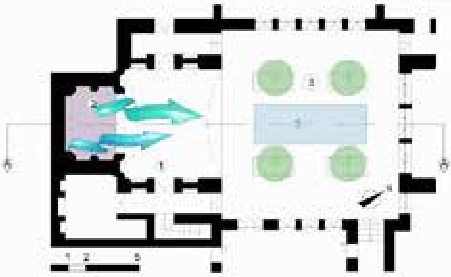
Wind-Box With One Opening

N. 2

Perspective



Plan L: 0



Passive cooling architecture strategies

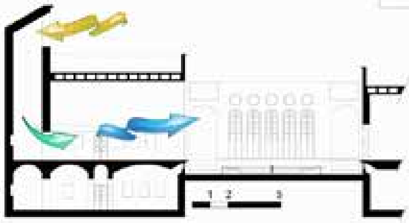
1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

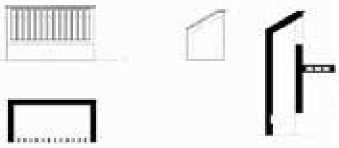
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	●
12. What are the special characteristics?	

Very large Wind-Box, favorable wind flow in the lower level.

Section





Number of Wind-Boxes

1

خانه کدخدا

این بنا در نزدیکی گذر اصلی محله بالا قرار دارد. که با عبور از یک کوچه بن بست نه چندان طویل می توان از گذر اصلی به آن دسترسی پیدا کرد. در نزدیکی خانه یک واحد تجاری نانوائی، آب انبار حاجی کریم و مسجد حاجی ملاحسین قرار دارد. وجود این سه عنصر مهم اهمیت این قسمت از محله را تا حد یک زیر محله بالا برده است. لذا خانه از موقعیت ممتازی از نظر دسترسی به خدمات شهری و مذهبی برخوردار است . وقتی از خانه به گذر فرعی و از آنجا به گذر اصلی می رسیم سه راه در پیش رو داریم. راه سمت شمال به میدان و مرکز محله پایین منتهی می شود. راه دست چپ به خیابان آیت ا... کاشانی و راه سمت غرب به مزار بالا.

تاریخ ساخت این خانه به اوایل دوره قاجار می رسد. متاسفانه نام معمار و بانی آن مشخص نبوده و هیچ گونه سند یا کتیبه نیز در خصوص خانه یافت نشده است. پس از درگذشت آقای محمدحسین کریمی (مالک اولیه) در حدود ۶۰ سال پیش برادرش آقای محمود کریمی آن را خریداری کرده و در آن ساکن می شود.

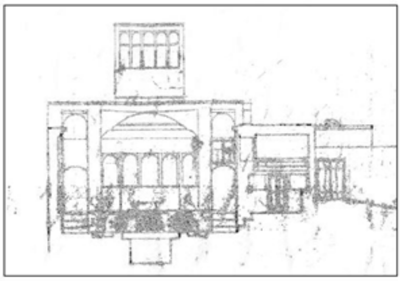
این بنا از گونه خانه های سه طرف ساخت می باشد. در ضلع شمالی، جنوبی و غربی فضا سازی شده و در ضلع شرقی فقط یک دیوار قاب بندی شده موجود است.

خوشبختانه کلیه فضاهای خانه و اغلب عناصر آن مانند کف، بازشوها، سقف و ... دست نخورده باقی مانده است. فقط در نقاط محدودی پوشش کف راهرو عوض شده و به جای آجر از موزائیک استفاده شده است.

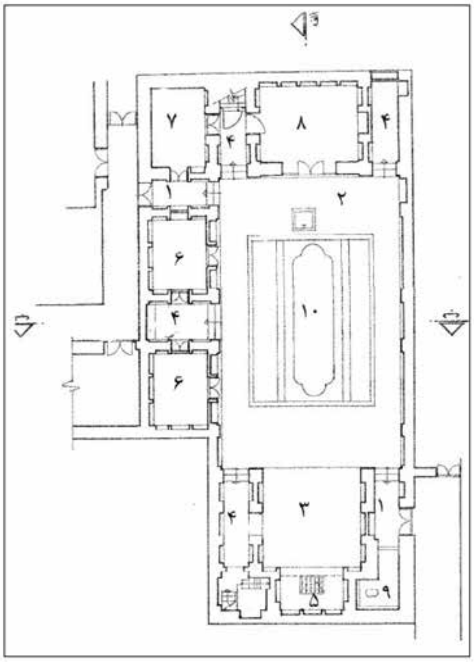
بدنه ضلع شمالی که شامل یک سه دری بوده تخریب و به جای آن یک بازشوی چوبی چهار لنگه نصب شده است.این بنا هم اکنون پا بر جا بوده و به جز از برخی نقاط در دیوارهای زیرزمین که رطوبت آن را فرسوده کرده است مشکلی ندارد و کلیه سقف ها سالم است.

کشیدگی مستطیل شکل حیاط با کشیدگی حوض مستطیل شکل میانی و باغچه های همجوار کاملاً هماهنگ می باشد . و ترکیب دلچسبی را هم در نقشه و هم در جوهره ی فضایی آن به وجود آورده است.

تا حدود ۱۰ سال پیش این خانه مسکونی بوده است اما پس از درگذشت آقای محمود کریمی (مالک آن) دیگر فرزندان وی در آن سکنی نگزیده اند و در حال حاضر متروک است.



نمای اصلی خانه کد خدا



پلان خانه کدخدا

۱- ورودی فرعی - ورودی اصلی
۲- حیاط
۳- ایوان
۴- راهرو
۵- بادگیر
۶- اتاق غربی
۷- مطبخ
۸- اتاق سه دری شمالی

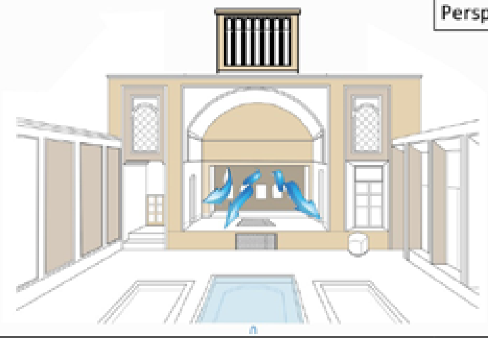
نمای اصلی خانه کدخدا

[Fig-13] Kadkhoda House (From: Cultural Heritage of Meybod), 100 Years Old

6.6.1.3 Case N.3 Wind-Box – Moazeni House, Ardakan, Iran

Real exmaple	Wind-Box With One Opening	N. 3

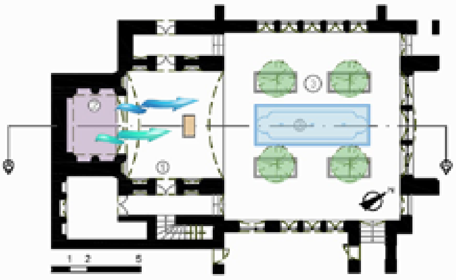
Perspectiv



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

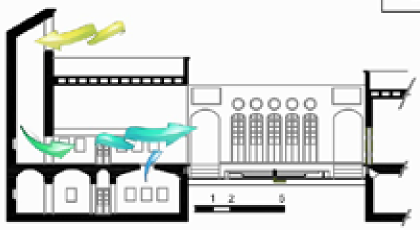
Plan L:0

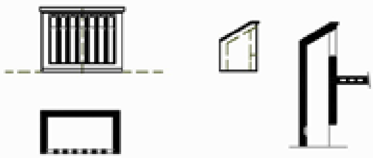


Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	●
3. Fountain in underground floor	○
4. Fountain in courtyard	○
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

Section





Number of Wind-Boxes
1

6.6.1.4 Case N.4 Wind-Box – Moafi-Alavi House, Meybod, Iran

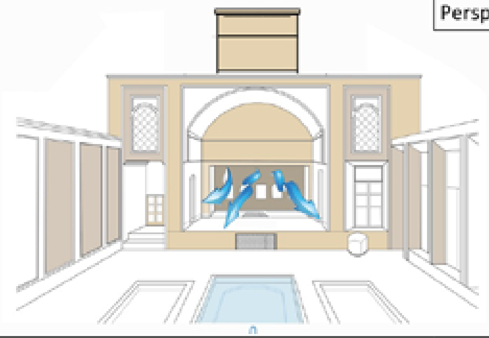
Real exmaple

منظر عمومی خانه معافی علوی از سمت بلوار ساخته شده در جوار آن

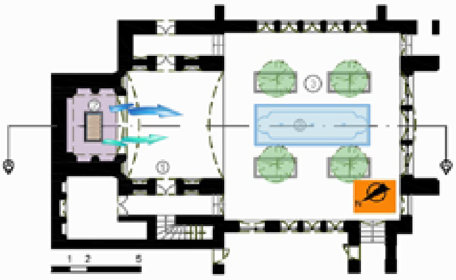
Wind-Box With One Opening

N.4

Perspectiv



Plan L:0



Passive cooling architecture strategies

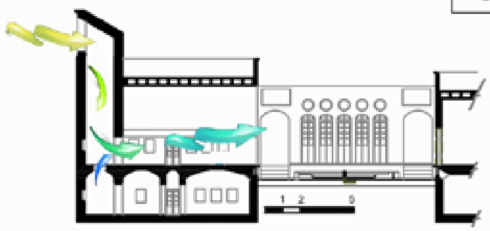
1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Indirect thermal mass cooling

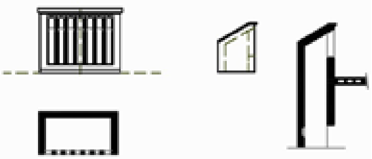
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	●
3. Fountain in underground floor	○
4. Fountain in courtyard	○
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	●
12. What are the special characteristics?	

Different Position of wind-Box

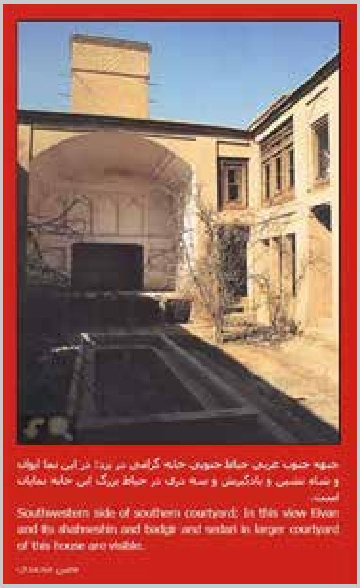
Section



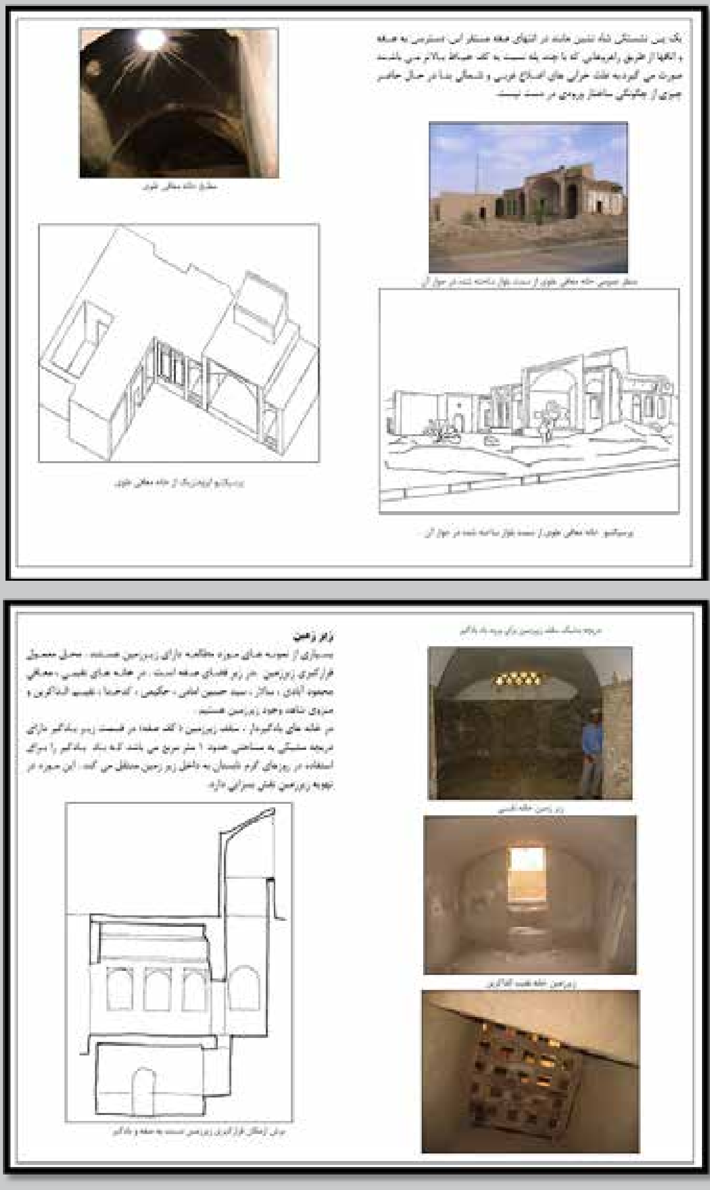


Number of Wind-Boxes

1



[Fig-14 Gerami House, Yazd (From:Moeen Mohamadi)



[Fig-15] Moafi-Alavi House in Ardakan, Indirect Mass Thermal Mass Cooling by the Aperture Between "Sardab and "Iwan" and Venturi Effect Between Them (From: Cultural Heritage of Meybod)

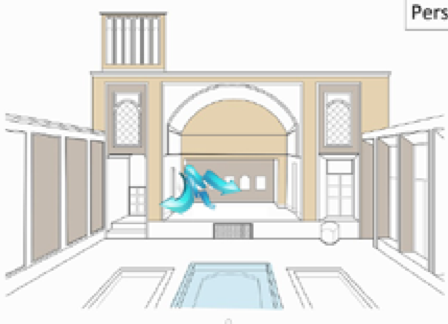
6.6.1.5 Case N.5 Wind-Box – Salar House, Meybod, Iran

Real exmaple

Wind-Box With One Opening

N.5

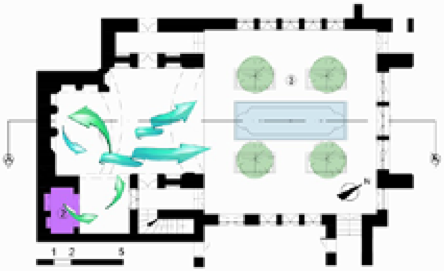
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

Plan L: 0



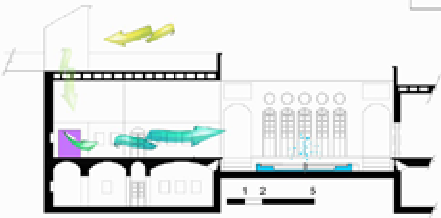
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	○
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	●

12. What are the special characteristics?

Wind-Box position is on the left side of the Iwan

Section



Number of Wind-Boxes

1

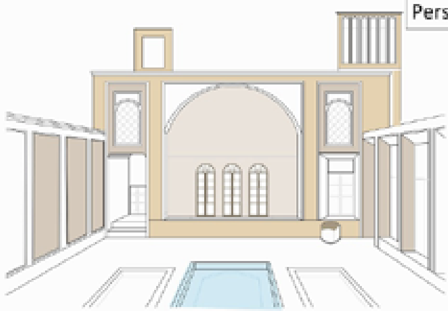
6.6.1.6 Case N.6 Wind-Box – Khatami House, Ardakan, Iran

Real exmaple

Wind-Box With One Opening

N.6

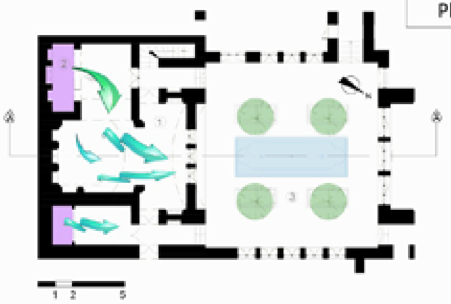
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

Plan L: 0



[Fig-16] Adib House, Gonabad, Iran

Passive cooling architectural elements

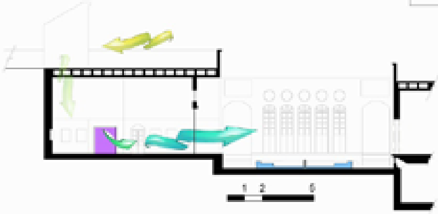
1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	○
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●

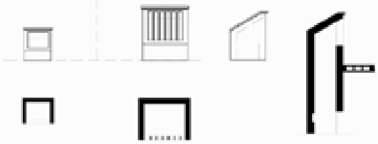
12. What are the special characteristics?

1.Wind-Bpx position is on the left side of the Iwan

2.There are two Wind-Boxes for two different spaces

Section



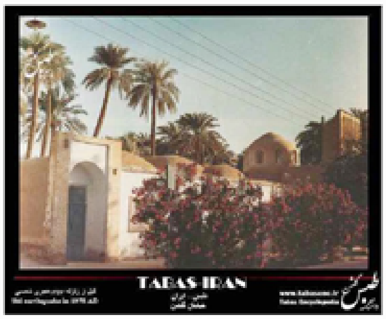


Number of Wind-Boxes

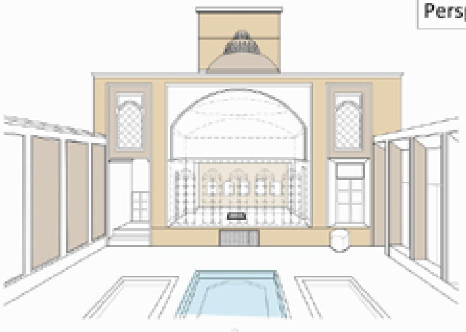
2

6.6.1.7 Case N.7 Wind-Box – House in Amir Garden, Tabas, Iran

Real exmaple	Wind-Box With One Opening	N.7



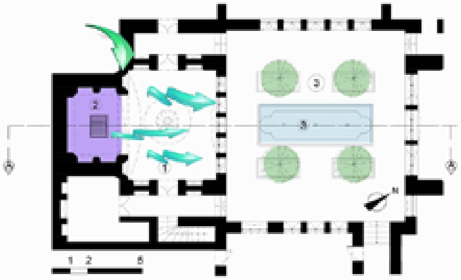
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky (Cupola, & all building mass)
7. Nighttime ventilation
8. Indirect Thermal mass
9. Increase air flow by expulsion of the warm air from the cupola
10. Possibility of control: indirect radiation and wind flow by vertical window.

Plan L: 0

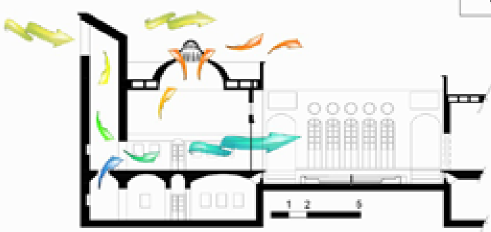


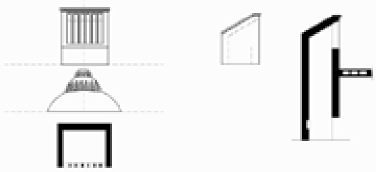
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	●
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	○
7. Wind-Tower in symmetry axes	●
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

1. Different direction of Wind- Box
2. Cupola and Wind-Box are in symmetry axes

Section



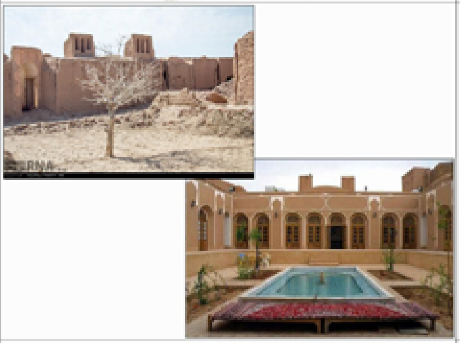


Number of Wind-Boxes

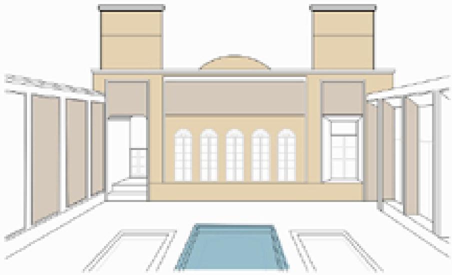
1

6.6.1.8. Case N.8 Wind-Box – Mohammadi House in Tabas, Iran

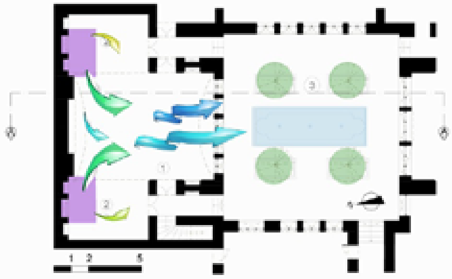
Real exmaple	Wind-Box With One Opening	N.8



Perspective



Plan L: 0

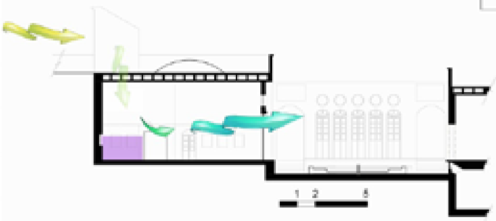


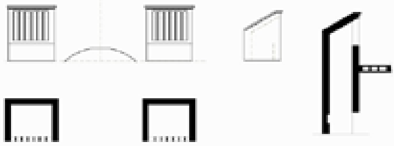
Passive cooling architecture strategies

1. Better Passive cooling ventilation
2. Evaporation
3. Direct thermal mass cooling
4. Lower sun daytime radiation
5. Nighttime radiation to sky
6. Nighttime ventilation
7. Possibility of control: indirect radiation and wind flow to courtyard

Passive cooling architectural elements	
1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	●
7. Wind-Tower in symmetry axes	●
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	
having two Wind- Boxes doubles the amount of wind that can enter the space	

Section





Number of Wind-Boxes
2

6.6.1.9 Case N.9 – Foruzanfar House

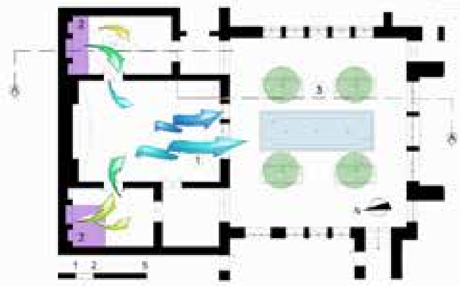
Real exmaple

Wind-Box With One Opening

N.9

Perspective

Plan L: 0



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. . Increase air flow by expulsion of the warm air from the cupola
9. Possibility of control: indirect radiation and wind flow by vertical window.

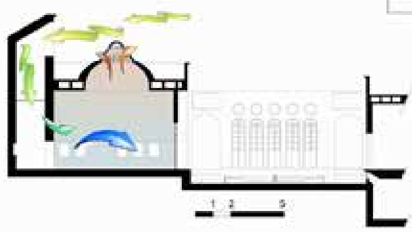
Passive cooling architectural elements

1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Boxes	●
7. Wind-Tower in symmetry axes	○
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●

12. What are the special characteristics?

The two Wind-Boxes increase the receiving wind from outside, and the cupola pushes out the interior warm air, making this system more functional. However, if the position of the cupola and Wind-Box is very close together, the warm air that comes out of the cupola will mix with the air that is entering the building.

Section

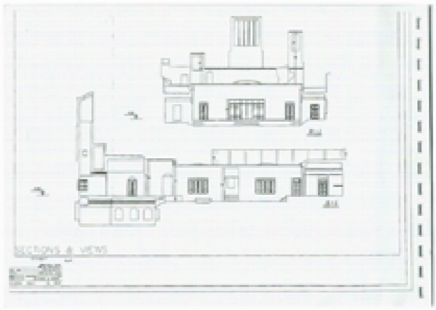


Number of Wind-Boxes

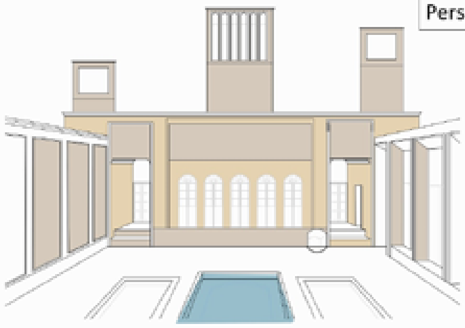
2

6.6.1.10 Case N.10 – Mahd-ol-Olama House

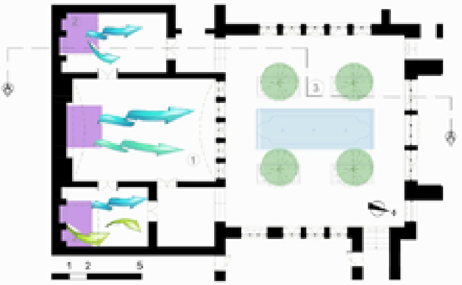
Real exmaple	Wind-Tower With One Opening	N.10



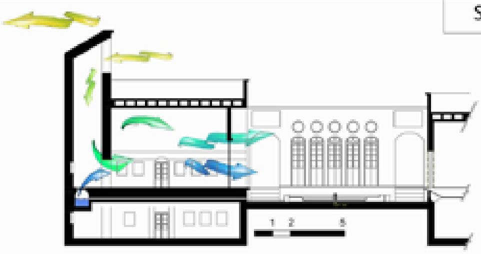
Perspective



Plan L: 0



Section



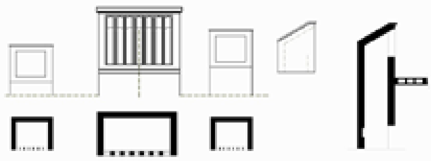
Passive cooling architecture strategies

1. Passive cooling ventilation
2. Evaporation of drinking water from the ancient city which passed through Iwan
3. Evaporation by fountain
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Indirect Thermal mass
9. Possibility of control: indirect radiation and wind flow by vertical window.

Passive cooling architectural elements

Element	
1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	●
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axes	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

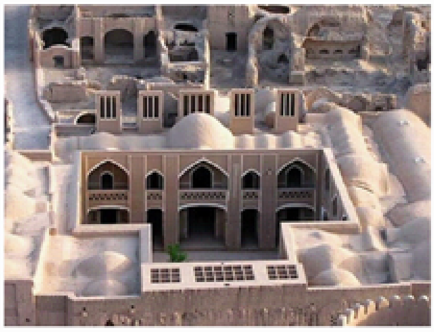
Passing the ancient city water through the duct under the Iwan created a very particular case study but unfortunately, the water source has dried out .



Number of Wind-Boxes
3

6.6.1.11 Case N.11Panj Bad-Gir in Bam

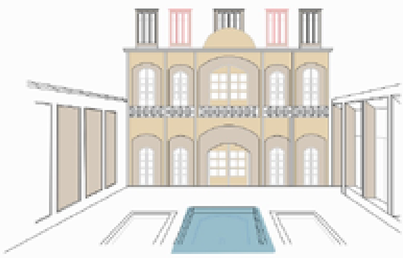
Real exmaple



Wind-Tower Withe One Opening

N.11

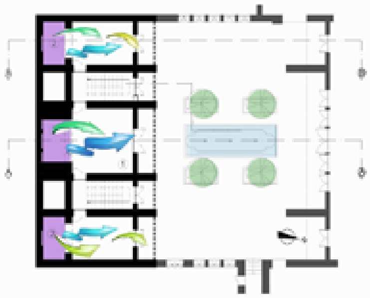
Perspective



Passive cooling architecture strategies

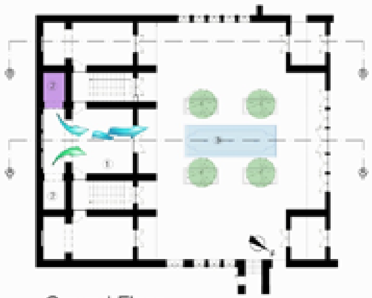
1. Passive cooling ventilation
3. Evaporation by fountain
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Indirect Thermal mass
9. Possibility of control: indirect radiation and wind flow by vertical window.

Plan L: 1

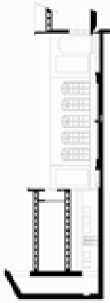


First Floor

Plan L: 0



Ground Floor



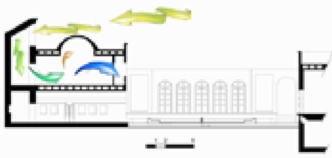
Section B-B

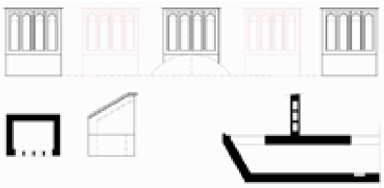
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

Two of the Wind-Boxes are connected to the ground floor and three of them are connected to the first floor.

Section A-A

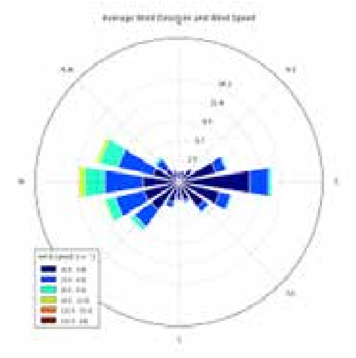




Number of Wind-Boxes

5

6.6.2 Typology B – Wind-Tower with Two Openings



[Fig-16]

The second category of traditional Iranian Bad-Girs in houses with a central courtyard are Wind-Towers that have two openings on their top. These Bad-Girs are usually not large and are located on the east or west sides of the courtyard, as their space is smaller than that of the north and south sides. They are directed towards the suitable primary local wind. [Fig-16]

As explained earlier, this typology has been used where the wind direction almost permanently remains in one direction or in two directions in the same axe, but with a 180-degree deviation. This is not a common type of Wind-Tower.

- <u>Capturing</u>: will happen when the wind is blowing in the direction of the Wind-Boxes' opening holes.
- <u>Expulsion</u>: will happen when the wind blows perpendicular to the openings' direction of the Wind-Tower. In this way, the Wind-Tower will work as an expulsion Wind-Tower.

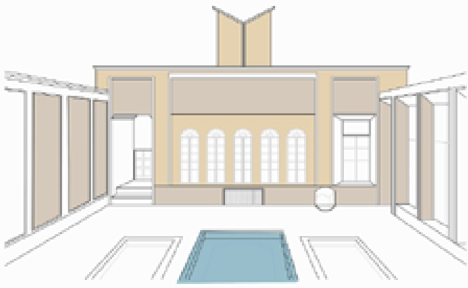
  In addition, at night when there is no wind blowing, it could work as a chimney to push out the warm air accumulated inside the home.

Location: Yazd, Aqda, Ardakan, Meybod, Rafsanjan

6.6.2.1 Case N.12 Sigariha house, Yazd

Real exmaple	Wind-Tower With Two Openings	N.12

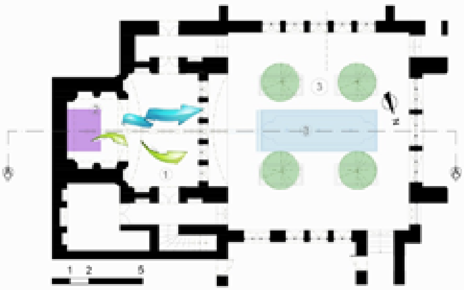
Perspective

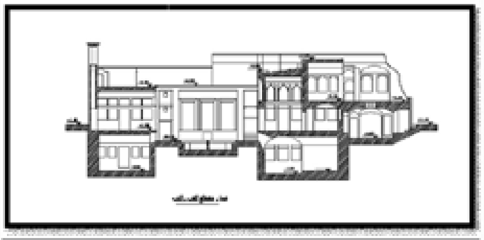


Passive cooling architecture strategies

1. Passive cooling ventilation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Indirect Thermal mass
9. Possibility of control: indirect radiation and wind flow by vertical window.

Plan L: 0





Other example: Section of Haj- Esmail- Marqun House

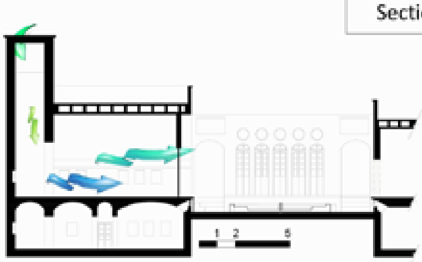
Passive cooling architectural elements

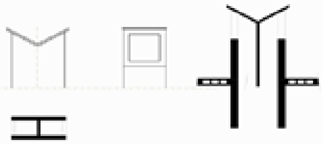
1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	○
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●

12. What are the special characteristics?

Iwan has a different position. It is located on the west side but it retreated the windows toward a deeper part, and this produced a good level of sun protection.

Section





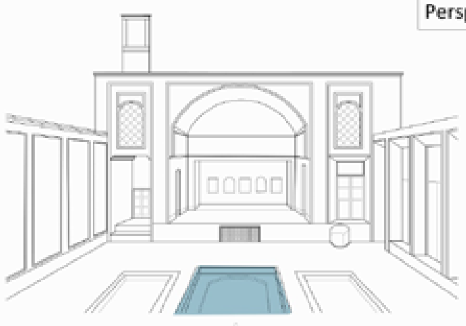
Number of Wind-Boxes

1

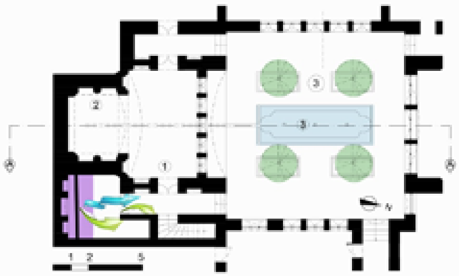
6.6.2.2 Case N.13 MIrza Rezahouse, Barood

Real exmaple	Wind-Tower With Two Openings	N.13

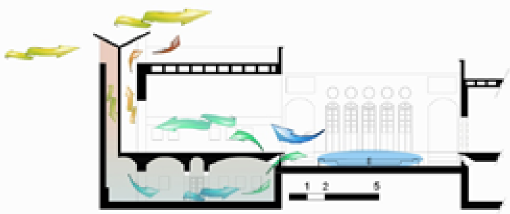
Perspective



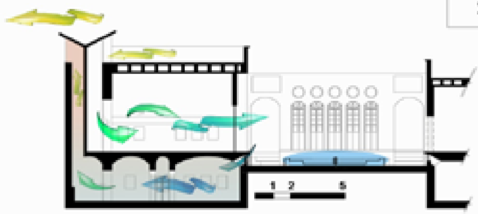
Plan L: 0



Section



Section



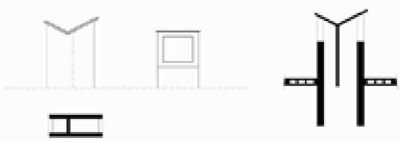
Passive cooling architecture strategies

1. Passive cooling ventilation
3. Evaporation by fountain
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Indirect Thermal mass
9. Possibility of control: indirect radiation and wind flow by vertical window.

Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	○
7. Wind-Tower in symmetry axe	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	●
12. What are the special characteristics?	

The opening of the larger duct is connected to the Iwan and the shorter duct is connected to the basement to produce more air circulation and decrease the humidity of underground part.



Number of Wind-Boxes
1

6.6.3 Typology C – Wind-Tower with Four or More Openings

The third category of traditional Iranian Bad-Girs in houses with a central courtyard are Wind-Towers that have four openings on their top. These Bad-Girs are usually large and tall and are situated on the South – South-West sides of the buildings. [Fig-17]These account for the largest number of Wind-Towers that still exist today.

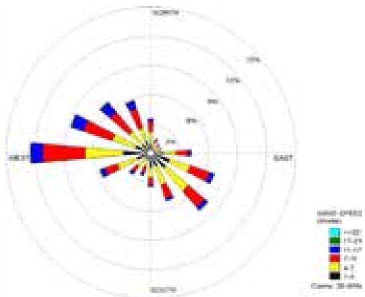
This typology has been used in cases where more than two wind directions exist, so that it can receive wind from any direction.

Capturing: will happen at any time to capture wind in any direction.

Expulsion: will happen when there is no wind blowing. It could function as a chimney to push out the warm air accumulated inside the home towards the outside.

A Wind-Tower with eight openings could be called a progressive form of a Wind-Tower with four openings. In the case of the Dolat-Abad Bad-Gir, which is the tallest one in Iran, the enormous size of this Wind-Tower allows for its body to absorb a huge amount of sun radiation in the afternoon, thus working as a solar chimney. Then, from the evening until noon-time of the following day, it loses its heat through radiation and convection, and it functions again as a Wind-Capture.

Location: Yazd, Aqda, Kerman, Sirjan, Isfahan, Semnan, Abarkooh



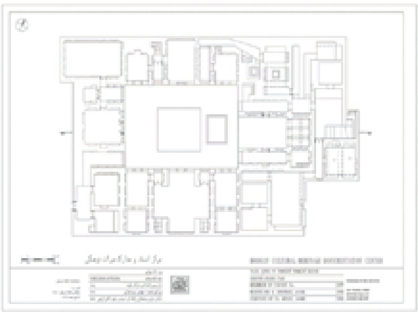
[Fig-17] Wind Diagram of Yazd

6.6.3.1 Case N.14 Tehrani house

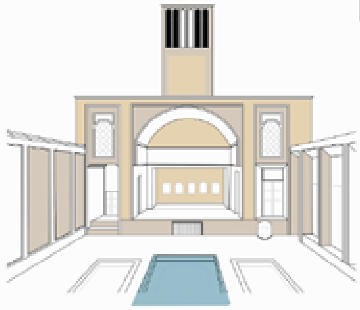
Real exmaple

Wind-Tower With Four Openings

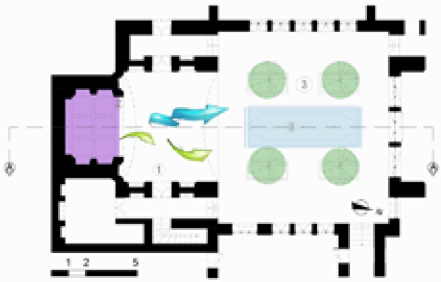
N.14



Perspective



Plan L: 0



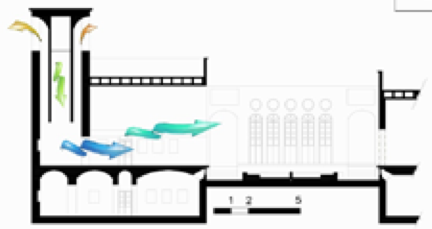
Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	○
7. Wind-Tower in symmetry axe	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

Section



Number of Wind-Boxes

1

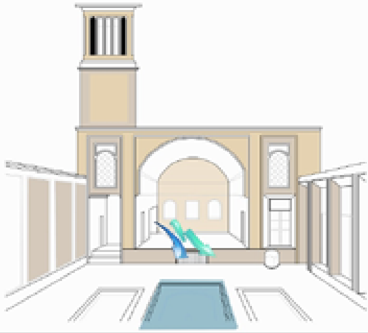
6.6.3.2 Case N.15 Ziarati house

Real exmaple

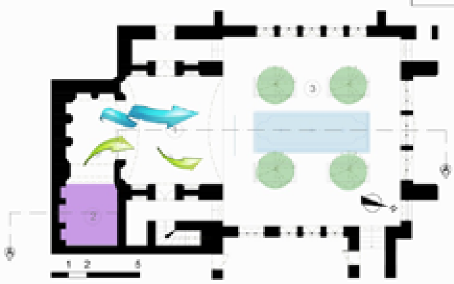
Wind-Tower With Four Openings

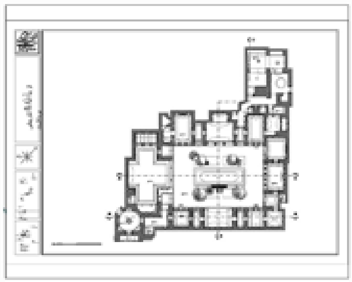
N.15

Perspective

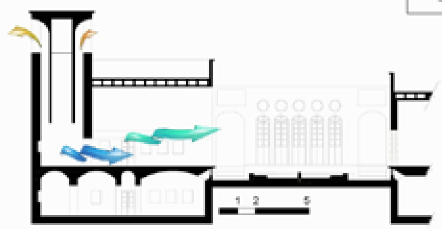


Plan L: 0





Section

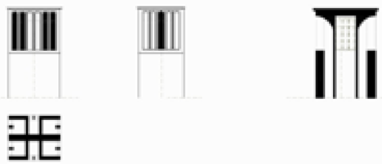


Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	○
7. Wind-Tower in symmetry axe	○
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

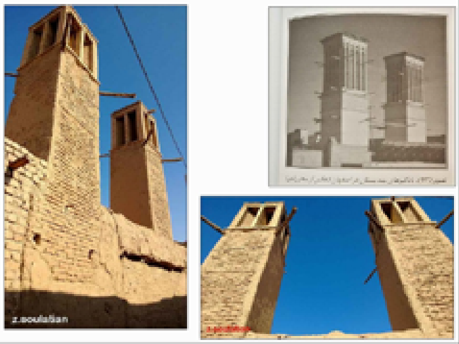


Number of Wind-Boxes

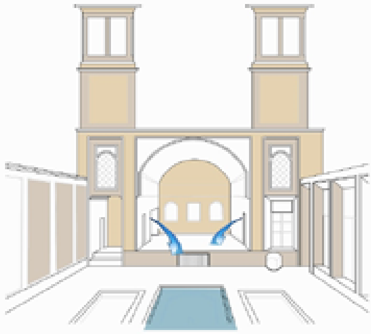
1

6.6.3.3 Case N.16 Mirza Reza house

Real exmaple	Wind-Tower With Four Openings	N.16



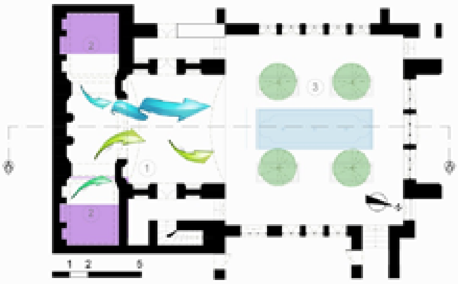
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

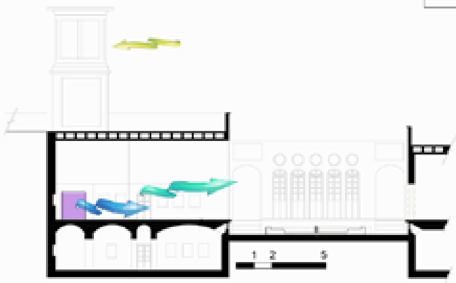
Plan L: 0

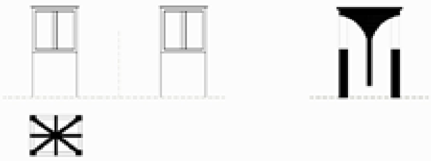


Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	○
9. Iwan fountain	○
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

Section

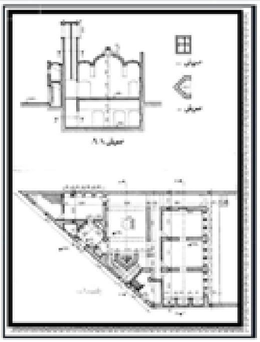




Number of Wind-Boxes
2

6.6.3.4 Case N.17 Haj Ali house

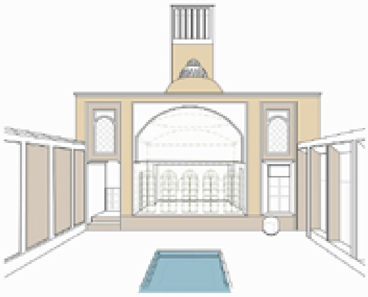
Real exmaple



Wind-Tower With Four Openings

N.17

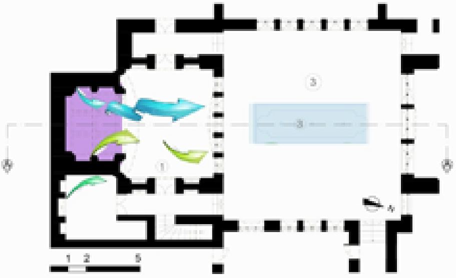
Perspective

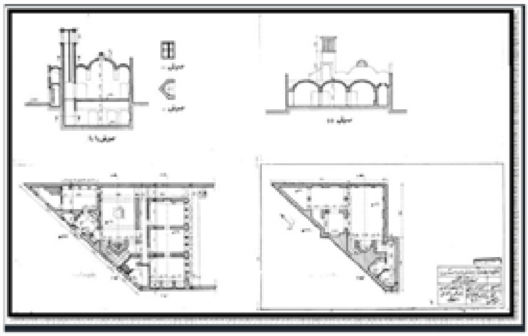


Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sunradiation
6. Nighttime radiation to sky (Cupola, & all building mass)
7. Nighttime ventilation
8. Indirect Thermal mass
9. Increase air flow by expulsion of the warm air from the cupola
10. Possibility of control: indirect radiation and wind flow by vertical window.

Plan L: 0

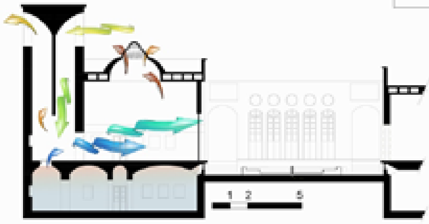


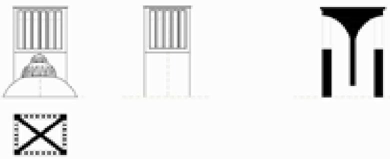


Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	●
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	○
6. Twin Wind-Tower or Wind- Box	○
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	○
12. What are the special characteristics?	

Section



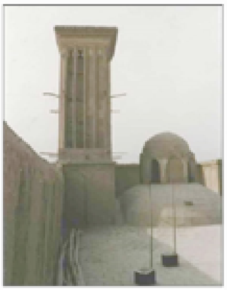


Number of Wind-Boxes

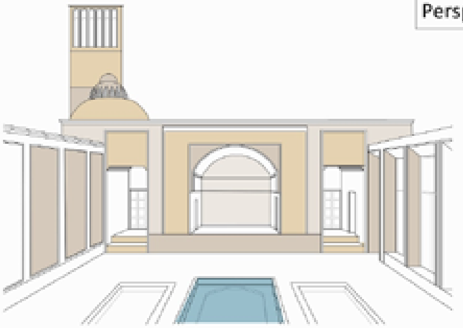
1

6.6.3.5 Case N.18 Shokuhi house

Real exmaple	Wind-Tower With Four Openings	N.18



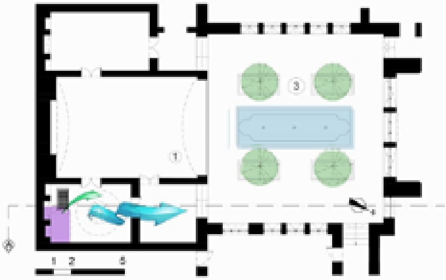
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky (Cupola, & all building mass)
7. Nighttime ventilation
8. Indirect Thermal mass
9. Increase air flow by expulsion of the warm air from the cupola
10. Possibility of control: indirect radiation and wind flow by vertical window

Plan L: 0

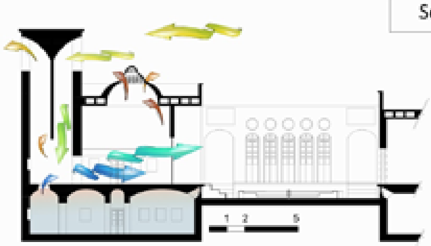


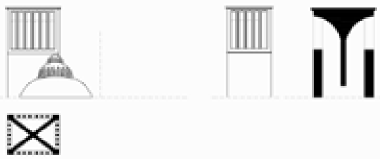
Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	○
7. Wind-Tower in symmetry axes	○
8. Cupola	●
9. Iwan fountain	○
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

The Wind-Tower and cupola are positioned in a small room that is located near the Iwan

Section





Number of Wind-Boxes
1

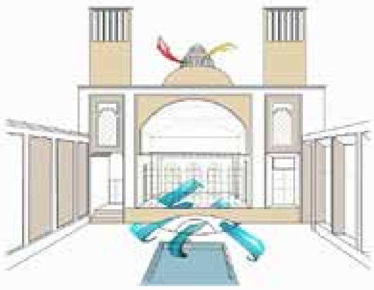
6.6.3.6 Case N.19 Borujerdiha house, Kashan

Real exmaple

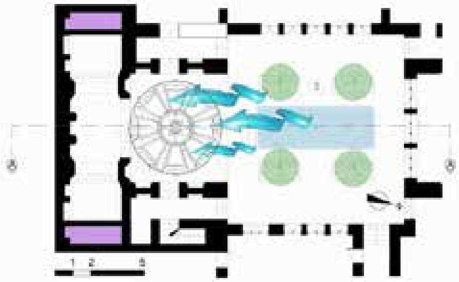
Wind-Tower With Four Openings

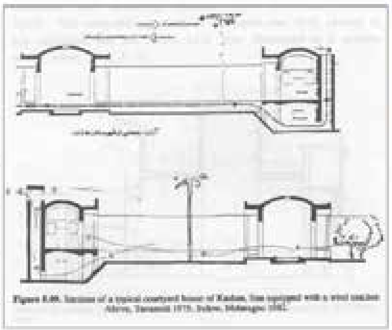
N.19

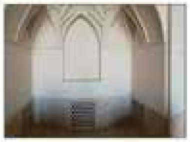
Perspective



Plan L: 0







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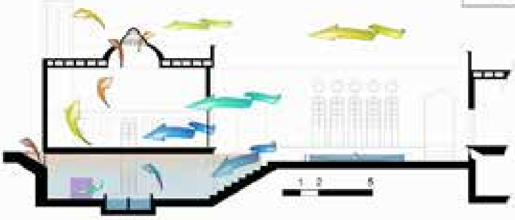


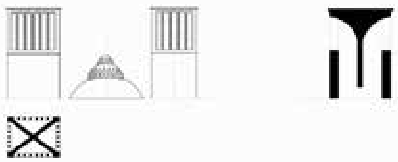
Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower daytime sun radiation
6. Nighttime radiation to sky (Cupola, & all building mass)
7. Nighttime ventilation
8. Indirect thermal mass
9. Increase air flow by expulsion of the warm air from the cupola
10. Possibility of control: indirect radiation and wind flow by vertical window

Passive cooling architectural elements

1. Underground floor	●
2. Connection with underground floor	●
3. Fountain in underground floor	●
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	●
10. Iwan vertical window to courtyard	●
11. Other special characteristics	○
12. What are the special characteristics?	

The cool and humid air over the courtyard fountain moves down to the basement and the Wind-Tower uses the termal mass through underground ducts, which decreases the air temperature. Then, the warm air exits from the top little window on the other side.



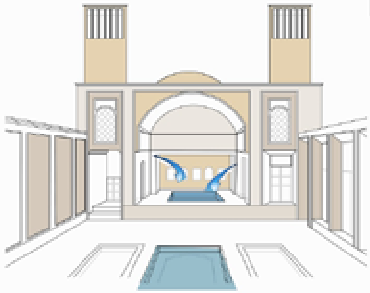
Number of Wind-Boxes

2

6.6.3.7 Case N.20 Abbasi house, Kashan

Real exmaple	Wind-Box With four Openings	N.20

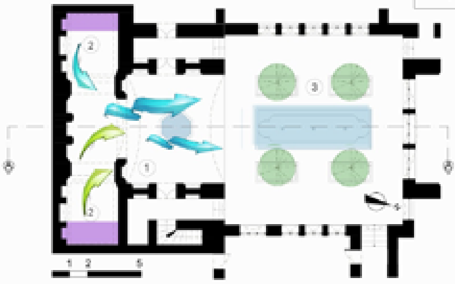
Perspective



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Evaporation
3. Direct thermal mass cooling
4. Lower sun daytime radiation
5. Nighttime radiation to sky
6. Nighttime ventilation
7. Evaporation inside the Iwan

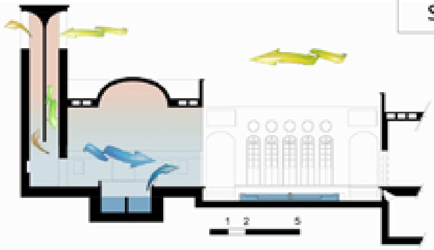
Plan L: 0

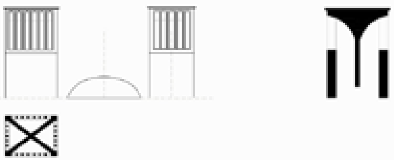


Passive cooling architectural elements

1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	●
10. Iwan vertical window to courtyard	○
11. Other special characteristics	○
12. What are the special characteristics?	

Section





Number of Wind-Boxes

1

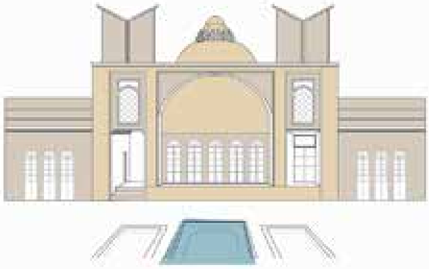
6.6.3.8 Case N.21 Kushk in Pahlavan Pour garden, Mehriz

Wind-Tower With two Openings

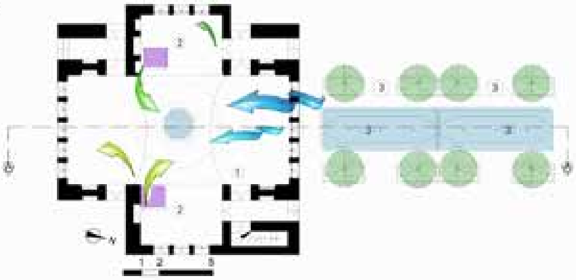
N.21

Real exmaple

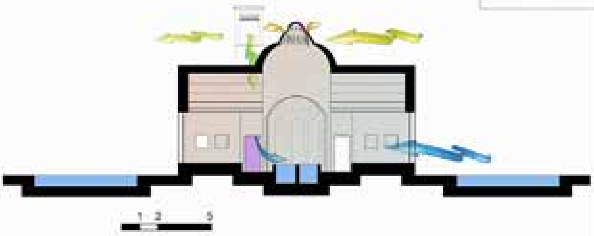
Perspective



Plan L: 0



Section



Passive cooling architecture strategies

1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation

Passive cooling architectural elements

1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	●
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

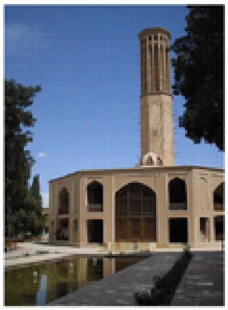
This typology usually can be found in "Kushk" Persian gardens. Twin Wind-Towers in conjunction with the cupola and interior fountain, can create a very comfortable ventilated space.

Number of Wind-Boxes

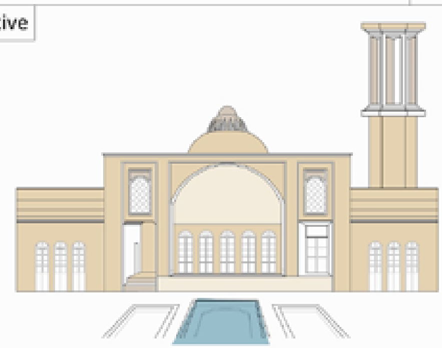
2

6.6.3.8 Case N.21 Kushk in Dolat Abad r garden, Yazd

Real exmaple	Wind-Tower With two Openings	N.22



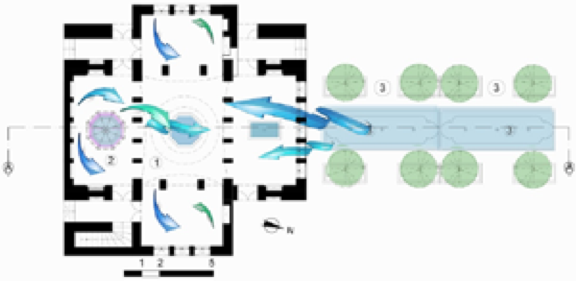
Perspective

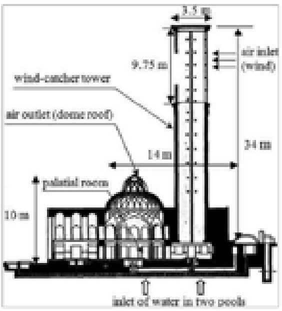


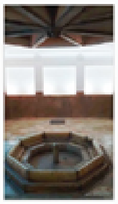
Passive cooling architecture strategies

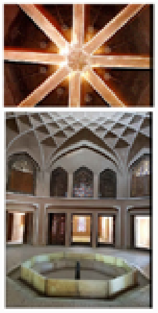
1. Passive cooling ventilation
2. Indirect thermal mass cooling
3. Evaporation
4. Direct thermal mass cooling
5. Lower sun daytime radiation
6. Nighttime radiation to sky
7. Nighttime ventilation
8. Evaporation by interior fountains
9. Thermal mass as solar chimney

Plan L: 0







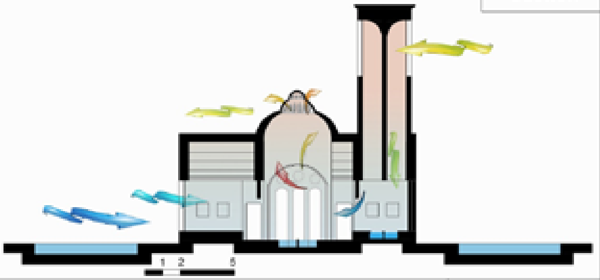


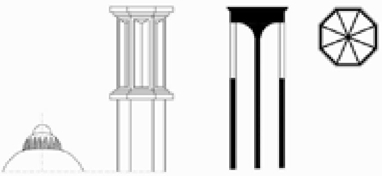
Passive cooling architectural elements

1. Underground floor	○
2. Connection with underground floor	○
3. Fountain in underground floor	○
4. Fountain in courtyard	●
5. Vegetation in courtyard	●
6. Twin Wind-Tower or Wind- Box	●
7. Wind-Tower in symmetry axe	●
8. Cupola	●
9. Iwan fountain	●
10. Iwan vertical window to courtyard	●
11. Other special characteristics	●
12. What are the special characteristics?	

It is the tallest Bad-Gir in the world
The Wind-Tower works to capture and expulse air
It uses interior fountains for additional evaporation
Marble material is used in the room where the Bad-Gir is located, and it improves thermal comfort
In the afternoon, the Wind-Tower works more as a solar chimney

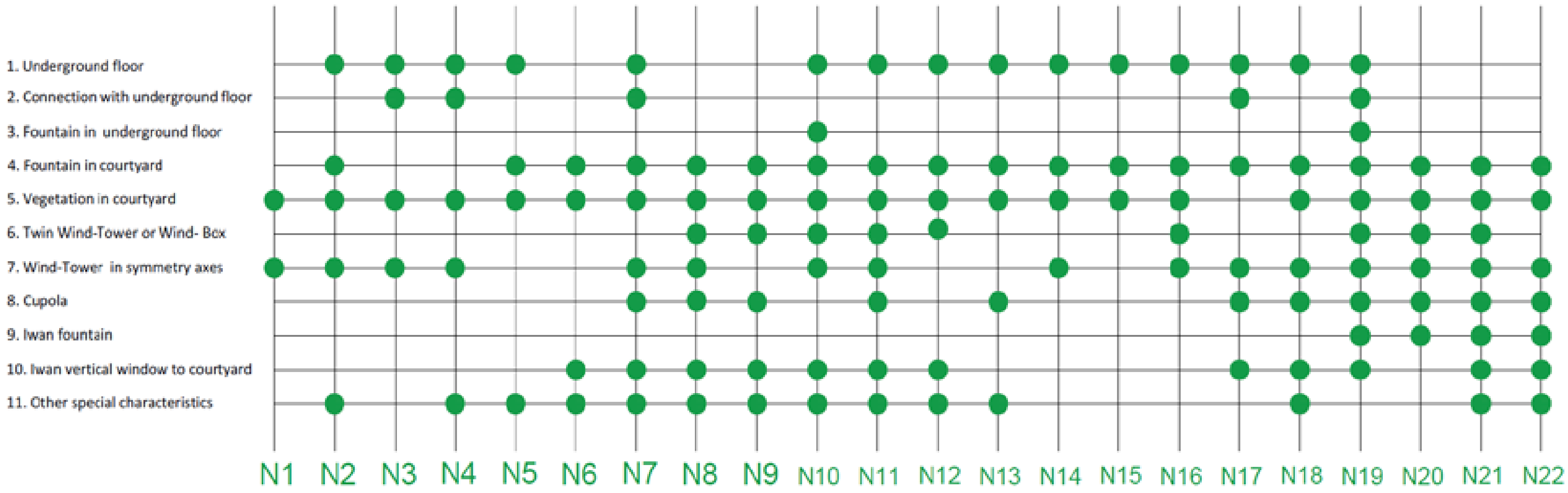
Section





Number of Wind-Boxes

1


1. Underground floor
2. Connection with underground floor
3. Fountain in underground floor
4. Fountain in courtyard
5. Vegetation in courtyard
6. Twin Wind-Tower or Wind- Box
7. Wind-Tower in symmetry axes
8. Cupola
9. Iwan fountain
10. Iwan vertical window to courtyard
11. Other special characteristics
N1
N2
N3
N4
N5
N6
N7
N8
N9
N10
N11
N12
N13
N14
N15
N16
N17
N18
N19
N20
N21
N22

6.7 Benefits and Defects of the "Bad-Gir"

Benefits:

- The main benefit of the Bad-Gir is that without consuming any money or other kind of energy, we can increase air movement and air-conditioning inside the building.
- This ancient innovation does not damage or conflict with our environment.
- It could be utilized anywhere because in every place in the world, there exists at least a minimum level of air movement.
- In any kind of hot climate areas – humid or dry – having air movement on the body helps with body evaporation, and thus improves the thermal comfort situation.

Defects:

- Using natural wind flow causes us to have little or no control over certain factors. For example, there are some dust and pollution that could enter inside the home through the air flow. In the case of a sand storm, a huge amount of dust could enter the home via its Wind-Tower.
- Birds and insects can enter the home, creating additional problems.
- Controlling the air flow that enters the home can be somewhat difficult. Therefore, there are some cases where traditional houses have a window under their Bad-Gir, which gives the possibility to close and open the holes by choice. This however, does not exist in all homes.
- Sometimes during high temperature hours of the day, there is a very low level of air flow and thus, the Bad-Gir's efficiency is not enough to create an acceptable thermal condition.
- The traditional house with a central courtyard is not appropriate for our modern lifestyle because their constructions come at a higher price and with the ongoing increases in world population, more and more people are constricted to live in apartments or houses that are smaller in size.
- The Wind-Tower/Box is part of a complex system that works together (fountain, Iwan, vegetation, cupola, basement, etc.) to create a better thermal comfort. It therefore, needs to collaborate with other elements in order to function properly.

6.8 Conclusion

All of these case studies have been chosen according to the various qualitative characteristics they each had, in particular, according to their specific Bad-Gir typologies. They were not chosen in relation to the quantity of case studies. The main objective was to discover how different traditional architectural elements can influence each other to create an improved thermal comfort inside each individual building in extreme hot climates.

By studying all of these cases in hot dry climates, twin Wind-Towers/Boxes, in collaboration with cupolas, could create a very strong air circulation in the space, because they increase the amount of air entering that can be captured and the cupola pushes out the warm air outside of the building. Thus, using these architectural elements could create a natural engine of air circulation without the use of any electrical instruments.

Underground floors consistently have a lower temperature, between 19°C to 23°C, and they have a very good potential to be used with ventilation to be able to cool down the air. If we incorporate this cold element with the passing of air circulation between the cupola and Wind-Tower, the temperature could also be decreased more than before.

By observing most of these cases, we can discern that the fountain has a principal role in cooling the courtyard temperature and creating a better thermal comfort.

CHAPTER 7

Contemporary Passive Cooling Strategies in Architecture (Focused on Natural Ventilation) Case Studies B

7.1 Objective

In the previous chapters (V and VI), the target was to more closely examine the cooling strategies in vernacular and traditional architecture in hot climate areas of the Middle East. It was very important to know all the strategies that could be used without any intervention of technology.
Human science has been on high speed in the last 80 years, particularly from 1950, when the digital revolution first began. This modernism has also had a direct effect on the field of architecture. Today, we can use new structure methodology, new materials, new insulators, new tools like computers and different software, cranes and various construction trucks, reinforced concrete, electricity, gas, and urban water plumbing.
Parallel to the changes in technology, our cultures and societies have also changed significantly and have caused a new identity, lifestyle, different habits and in addition new architectural forms. Today, we are used to living in skyscrapers with air conditioning.
Given the awareness of environmental cleanliness, global warming and the importance of low energy consumption, over the last 20 years, fields like zero energy housing, environmental architectural technology, and passive cooling and warming systems in architecture have become more important.
In various contemporary architectural projects, architects and engineers have been using different passive strategies to create a cooler environment with lower consumption of energy. According this target, they applied new technology and scientific rules to make a better and safer architecture.
In this chapter, we will study a number of case studies in contemporary architecture that have been treated with natural ventilation and passive cooling technology in their architecture, and as a target, we want to see which contemporary strategies here were not used in the ancient vernacular architecture of hot climate areas.

7.2 Case Studies

The case studies in this section were selected to demonstrate passive architecture using cooling systems with ventilation.

7.2.1 **Case N.1**: De Montford University – Queens Building in Leicester, UK

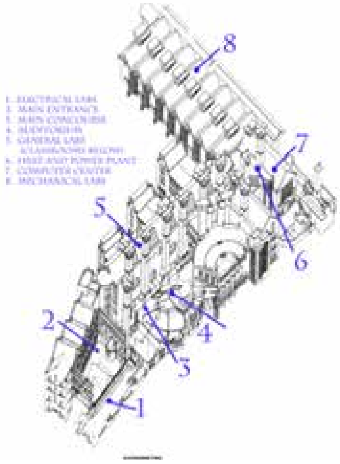
"The Queens Building [Fig-1] *at De Montfort University in Leicester was completed in 1993 and contains two solely naturally ventilated 180-seat wide-fan lecture theaters. It represents the first attempt by the architects, Short and Associates, to make a naturally ventilated auditorium. The natural ventilation strategy is buoyancy-driven displacement ventilation assisted by tall stacks (two per auditorium), identifiable by the CO2, readings, which rise to a peak of 1682 ppm. Guidance on air quality standards for teaching spaces given in Building Bulletin BBI0I (DfES, 2006) recommends that the average and maximum CO2 concentrations should not exceed 1500 ppm and 5000 ppm, respectively. The temperatures do not rise significantly above their nighttime set-point temperatures of 20°C, illustrating the damping effect of the thermal mass exposed around the walls and ceiling of the auditorium. More interesting is the capacity of the thermal mass effect to hold internal temperatures below the external (ambient) temperature throughout the occupied period. The design process and post-occupancy monitoring of the Queens Building led the design team to the following important findings, which were used in the development of subsequent projects incorporating natural ventilation:*

- *The minimum required ventilation rate of five air changes per hour (ACH) for fresh air was almost always achieved with case in both summer and winter.* [1]

- *In heating mode, with a high buoyancy force, the stack effect was found to be too great* [2] *and finer control was required to provide smaller opening sizes to prevent cold draughts. Damper settings were designed to vary in 25 % increments, giving only five positions.*

- *The single-stage preheat strategy was too crude and air could bypass the finned tube units, particularly directly above the inlet openings into the base of the plenum. The conventional proprietary dampers appeared to leak in their fully closed mode.* [3] *These findings influenced the designers' approach to the natural ventilation strategy for the later Coventry University Library, [4] incorporating two-stage preheating and high performance dampers, developed by the manufacturers specifically for the project.*

- *The beneficial effect of the thermal mass is noticeable, especially when coupled with nighttime ventilation, achieving a 1-degree fabric temperature rise (ceiling) over five days during daytime periods of 26°C ambient temperature and high occupancy. Typically, five degree internal fluctuations in temperatures are recorded against 13 to 14 degree external fluctuations. Howarth (1997) has suggested that the concrete-lined plenum is effective in damping the temperature of incoming air during the day, particularly after it has been subjected to nighttime ventilation.*" [5]

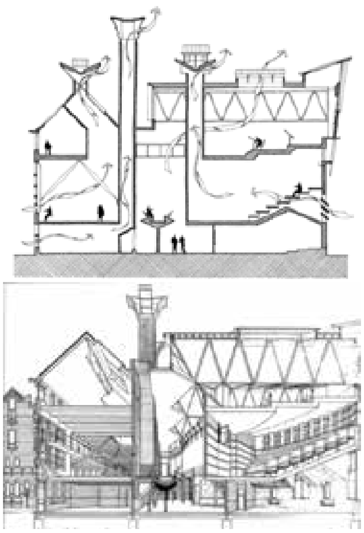


[Fig-1] Top: View of the Queens Building, De Montfort University; Bottom: Perspective of University (From: Case study by C. Megan Compton, Spring 2006)

Bottom of Form

"The intention was to tackle and face this environmental morale problem of the campus and the neighborhood and to make a building that was as naturally conditioned as possible." Alan Short, Dimensions of Sustainability.

Marks Heeley Ltd. was engaged by Galliford Try as part of their design and build bid for a major refurbishment of the structural/mechanical Laboratories at De Montford University, Leicester. The works generally comprised the provision of a large mezzanine floor with office accommodation over and link bridges to existing surrounding mezzanine walkways. Employer's information provided structural engineering proposals in respect to the works and providing a large number of internal columns to the ground floor footprints. Marks Heeley Ltd. developed an alternative solution making use of long span asymmetric cell beams with an inositol composite concrete slab on super holorib decking. Feature columns were provided using circular hollow sections and adjacent the existing perimeter walls of the laboratory buildings. [Fig-2]



[Fig-2] Top: Airflow in Amphitheatre; Bottom: Section Perspective of Amphitheatre (From: Case Study by C. Megan Compton, Spring 2006)

Design Intent and Validation:

The floor plan of this building was dictated by the architect's goal of designing a naturally ventilated building. The labs have a narrow floor plan and operable windows to allow for cross-ventilation. [Fig-2] *The main floor has a wider floor plan which cannot rely on windows for cross-ventilation, so eight, large venting chimneys were constructed to exhaust warm stale air created by the people and computers. These chimneys rely on the stack effect to operate properly. When the temperature difference in the air between the top and bottom of the flue is greater than that of the air outside, "warm air vents out." This effect draws in cooler air through the vents that are lower in the building, cooling down the building. The architects first designed fewer chimneys, but later increased the number so that now two spaces need to share one. To ensure that all the chimneys were built, Short and Ford designed them to be structural, so budgetary concerns could not determine their importance and cut them out of the construction process. The building's brick enclosure acts as a thermal wrapper, buffering the building from temperature peaks at midday. The brick also acts as a noise barrier, isolating the noise created by the mechanical labs. The load-bearing brick façade was chosen because the university wanted the construction of the building to create job opportunities during the construction phase. Wide insulation-filled cavity walls and concrete slabs in the ceiling create thermal mass which absorbs the heat during the day while the space is occupied and releases it at night, when the building in empty."* [6]

"The building was designed to have three different parts. The first one is the two wings of electrical laboratories that create an entrance courtyard. As the building increases in floors, the floor plan increases as well to minimize the direct sun that penetrates the three floors of the laboratories. Small windows with deep reveals were used to decrease the amount of direct solar gain. Within this space, there are light shelves which bounce the daylight off the ceiling deeper into the space. The courtyard walls are painted white to bounce the light down into the lower levels. The second part of the building is the central building. It has the eight chimneys piercing through the double-height concourse, which creates a separation between the labs and the auditoria. This space creates a comfortable meeting area in the winter. The roof is broken up to allow for natural light to penetrate deep into the space and to exhaust the warm air in a stack effect. The daylight was intended to reduce the need for electrical lighting. The ramps throughout this space contain glass brick to allow light to pass

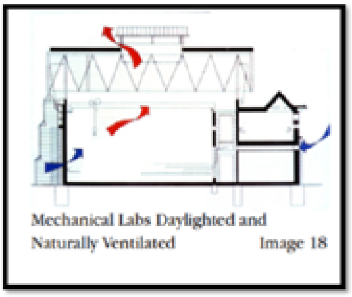
through it. In general, lab top-lighting is used to bring light into the space. In the offices, auditoria, studios, and computer labs, side-lighting is implemented to allow light to enter the space. In the auditoria, fresh air enters through louvers in the north façade by means of plenums below the raked wooden floor and wall inlets, which are controlled by the BEMS, allowing ventilation throughout the space. Two 133-meter-high chimneys ventilate the space.
The third part of the building houses the mechanical labs. This part of the building is located around the corner from the central building and is delineated by its peaked roofs. The gabled street façade is covered with large windows allowing natural daylight to enter the space without introducing too much glare. "Gantries inside run parallel to the roof ridgeline, supported on one side by exterior brick piers. Each of these buttresses, its brick coursing perforated, doubles as an air intake louver." (Philip Arcidi). The mechanical labs implement top-lighting like the general labs, to bring light into the spaces.

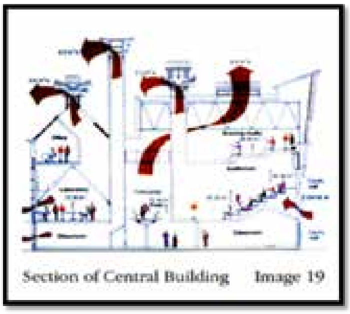
Daylighting:
The central concourse has large roof lights that allow for deep sun penetration. Offices, studios, auditoria, computer labs, and classrooms are side-lit by small windows [Fig-3] with deep reveals on the east and west to control the amount of thermal gain, but still let in fresh air and daylighting. Narrow floor plans, with external courtyard and white painted walls were designed to bounce light into the interior spaces. Light shelves are used in the electrical labs. Top lighting is used in the mechanical and general labs. Glass brick ramps in the main circulation space allow light to pass through to light the space underneath. The electrical lab floor plans increase in width as the floors go up, which block the direct sunlight and reduce the thermal gains.

[Fig-3] Top: Receives Natural Light from Top; Bottom: Little Windows (From: Case Study by C. Megan Compton, Spring 2006)

Thermal Mass:
The building was built of brick creating a large amount of thermal mass, which helps to stabilize the temperature fluxes.

Natural Ventilation:
Chimneys were constructed to create a stack effect, which would allow the building to ventilate the hot, stale air and bring in fresh, cool air. Cross-ventilation was used whenever the floor plans allowed for it. The condensing boiler provided approximately 45% of the yearly heat energy. The conventional boilers, together account for 41%, and the





[Fig-4] Wind Flow: Left: in Mechanical Lab; Right: In Amphitheatre (From: Case Study by C. Megan Compton, Spring 2006)

CHP uses 14%. The CHP unit will not make any significant financial savings over its lifetime, but it will make a positive contribution to the reduction of CO2 emissions by about 30 tons per year.
Lighting consumption makes up most of the electrical power use (in 1994). Now that everyone has computers, I believe that has changed.
Occupancy Survey:
"Overall, the perception of thermal comfort and air quality is similar to national benchmarks, and overall air quality in winter is considered to be significantly better than benchmark… Combination of thermal mass and natural ventilation was effective at maintaining a comfortable environment for most of the building during the summer of 1994" (Bordass 1997)." [Fig-4] [7]

Brief of Strategies:

- **Thermal mass by bricks**
- **White painting to have more reflection**
- **High chimneys**
- **Natural lighting**
- **Transparent bricks to use more lighting**

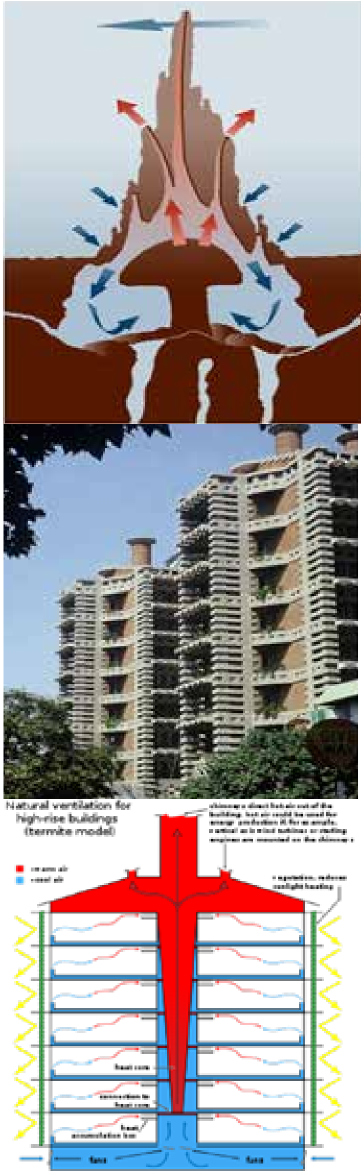
7.2.2 **Case N.2**: The Eastgate Centre in Harare, Zimbabwe

“The Eastgate Centre is a shopping center and office block in central Harare, Zimbabwe whose architect is Mick Pearce. Designed to be ventilated and cooled by entirely natural means, it was probably the first building in the world to use natural cooling to this level of sophistication. It opened in 1996 on Robert Mugabe Avenue and Second Street, and provides 5,600 m² of retail space, 26,000 m² of office space and parking for 450 cars.

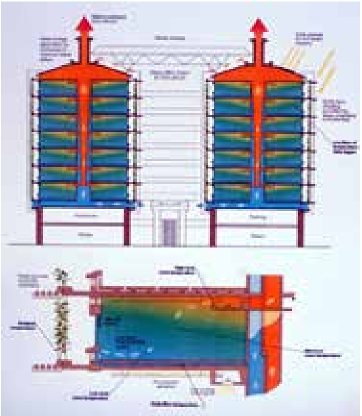
Designing for Thermal Control:
The Eastgate Centre’s design is a deliberate move away from the “big glass block.” Glass office blocks are typically expensive to maintain at a comfortable temperature, needing substantial heating in the winter and cooling in the summer. They tend to recycle air, in an attempt to keep the expensively conditioned atmosphere inside, leading to high levels of air pollution in the building. Artificial air-conditioning systems are high-maintenance, and Zimbabwe has the additional problem that the original system and most spare parts have to be imported, squandering foreign exchange reserves. Mick Pearce, therefore took an alternative approach. Because of its altitude, Harare has a temperate climate despite being in the tropics, and the typical daily temperature swing is 10 to 14 °C.” [8]

Passive Cooling:
“Passive cooling works by storing heat in the day and venting it at night as temperatures drop.
- Start of day: the building is cool.
- During day: machines and people generate heat, and the sun shines. Heat is absorbed by the fabric of the building, which has a high heat capacity, so that the temperature inside increases but not greatly.
- Evening: temperatures outside drop. The warm internal air is vented through chimneys, assisted by fans but also rising naturally because it is less dense, and drawing in denser cool air at the bottom of the building.
- Night: this process continues, cold air flowing through cavities in the floor slabs until the building’s fabric has reached the ideal temperature to start the next day.

Passively cooled, Eastgate uses only 10% of the energy needed by a similar conventionally cooled building.” [9]



[Fig-5] The Eastgate Centre: Top: View; Middle Diagram of Air-Conditioning System in Termite Nets Bottom: Passive Natural Ventilation System in the Eastgate Centre



Continue of [Fig-5] The Eastgate Centre: Passive Natural Ventilation System in the Eastgate Centre

"They said that no direct sunlight must fall on the external walls at all and the north façade (direction of summer sun) window-to-wall area must not exceed 25%. They asked for a balance between artificial and external light to minimize energy consumption and heat gain. They said all windows must be sealed because of noise pollution and unpredictable wind pressures and temperatures, relying on ducted ventilation. Above all, windows must be light filters, controlling glare, noise and security." [10] *Passive cooling systems are particularly appropriate for this part of Africa because, long before humans thought of it; passive cooling was being used by the local termites. Termite mounds include flues, which vent through the top and sides, and the mound itself is designed to catch the breeze. As the wind blows, hot air from the main chambers below ground is drawn out of the structure, helped by termites opening or blocking tunnels to control air flow."* [11]

Termites in Zimbabwe build gigantic mounds inside of which they farm a fungus that is their primary food source. The fungus must be kept at exactly 87 ° F (30.5 °C), while the temperatures outside range from 35 °F (1 °C) at night to 104 °F (40 °C) during the day. The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature. [Fig-5]

"The Eastgate Centre, largely made of concrete, has a ventilation system which operates in a similar way. Outside air that is drawn in is either warmed or cooled by the building mass depending on which is hotter, the building concrete or the air. It is then vented into the building's floors and offices before exiting via chimneys at the top. The complex also consists of two buildings, side by side, that are separated by an open space that is covered by glass and open to the local breezes.

Air is continuously drawn from this open space by fans on the first floor. It is then pushed up vertical supply sections of ducts that are located in the central spine of each of the two buildings. The fresh air replaces stale air that rises and exits through exhaust ports in the ceilings of each floor. Ultimately, it enters the exhaust section of the vertical ducts before it is flushed out of the building through

chimneys.
The Eastgate Centre uses less than 10% of the energy of a conventional building its size. These efficiencies translate directly to the bottom line: Eastgate's owners have saved $ 3.5 million alone because of an air-conditioning system that did not have to be implemented. Outside of being eco-efficient and better for the environment, these savings also trickle down to the tenants whose rents are 20 % lower than those of occupants in the surrounding buildings." [12]

Brief of Strategies:

- **Thermal mass (concrete) cooling**
- **Using the chimney effect in the center of the building to pull out the warm air and adding electric ventilators on the first floor (natural ventilation using termites to passively cool their nests)**
- **Natural lighting**
- **Covering the building faces to have no direct sunlight**
- **Using insulated windows for noise and heat**

[Fig-6] The Regional Animal Campus, Texas

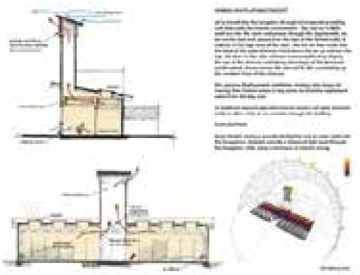
7.2.3 Case **N.3**: The Regional Animal Campus (The Animal Foundation Dog Adoption Park) in Las Vegas Valley, USA

The Regional Animal Campus [Fig-6] *for Las Vegas Valley (in August 2005) is intended to serve the animal sheltering and adoption needs for Las Vegas, North Las Vegas, and surrounding Clark County. Driven by a need to expand its operations, the Animal Foundation is developing plans to create a regional animal campus. The dog adoption park is the project's first phase.*
The dog adoption park consists of "dog bungalows," each containing 12 kennels, outdoor runs, and a visitation room. The bungalows are arranged in a park-like setting shaded by freestanding canopies supporting photovoltaic panels.
This project was chosen as an AIA Committee on the Environment Top Ten Green Project for 2006. It was submitted by Tate Snyder Kimsey Architects, in Henderson, Nevada. Additional project team members are listed on the "Process" screen.

Design & Innovation:
Predesign: From the outset, the non-profit status of the Animal Foundation influenced the design team's efforts. A long-time supporter of the Animal Foundation, the architect for this project also assumed a leadership fundraising position.
Because the Foundation's goals for the project exceeded the available budget, contingency strategies were developed to allow green measures to be phased in over time. This resulted in the design of a dual infrastructure: a conventional system tied into the campus' existing non-renewable infrastructure and a second system supporting renewable energy. Concurrently, the design team spearheaded successful grant applications to fund the purchase of renewable energy systems. The success of these efforts led to the construction of the green energy systems at the time of construction of the bungalows.

Design:
When the design of the dog adoption park was begun, the City of Las Vegas building code did not allow design methods and material uses that the design team considered essential to green building. As this was the first green project within the City's jurisdiction and on City property, it became an opportunity for the design team to partner with building officials to develop codes and acceptable construction meth-

ods to enable LEED(r) certification and other green projects. This was a dynamic process that continued throughout design and construction. As a result, City of Las Vegas building codes now provide a cogent framework for the review and approval of green buildings. Modeling was an essential tool during the design process. The design team relied heavily on EcoTect, an environmental program that is used to calculate daylighting, internal room comfort, building insolation, and the impact of building site massing on thermal performance. The building form and wind tower design were further modeled using aerodynamics software to ensure the efficiency of the passive cooling system.



[Fig-7] Orientation and Air Flow in The Regional Animal Campus, Texas

***Bioclimatic Design**:*
The dog adoption park bungalows' massing and orientation were derived from strategies to harvest the site's natural light and wind. The region experiences more than 300 sunny days per year. The site's wind patterns have primarily two seasonal variations: during the winter, winds are intermittent and predominantly from the northwest; during the summer, winds are frequent, hot and dry, and predominantly from the southwest.
Individual bungalows are organized in narrow blocks oriented along an east-west axis. Large windows on the north and south façades, in combination with the narrow section, allow daylight to reach the entire bungalow. Deep overhangs shade south-facing windows throughout the year, preventing glare and excess heat buildup. The bungalows' orientation prevents early-morning and late-afternoon summer light penetration while allowing direct winter morning and evening light for additional warmth in the minimally heated structure. The bungalows' form, distinctive towers, and airfoil were guided by the site's wind conditions. The bungalows' angled roofs shelter the dog runs and viewing walks while the uplift added to the wind immediately above the bungalows increases the efficiency of the cooling towers. [Fig-7]

Light & Air:
The bungalows have a large amount of daylight, and makeup lighting is provided by efficient fluorescent fixtures. The bungalows' narrow section and large windows create a visual connection between the interior and exterior, allowing prospective adopters to view animals from the outside with minimal disruption to the animals. [Fig-8]
They are passively ventilated during temperate periods with sensor-controlled operable louvers installed at the floor level. There are

[Fig-8] Top: View from Inside; Below: View from Outside

permanent openings at each dog kennel and in the wind tower.
The bungalows are minimally heated. The concrete slab in the kennels is heated by electric cables to provide a constant 80°F temperature for the dogs' comfort. During the cooling season, when indirect evaporative cooling is in effect, it is anticipated that indoor carbon dioxide levels will match outdoor levels. During temperate seasons, carbon dioxide levels will not exceed 500 parts per million.

Energy Flows & Energy Future:

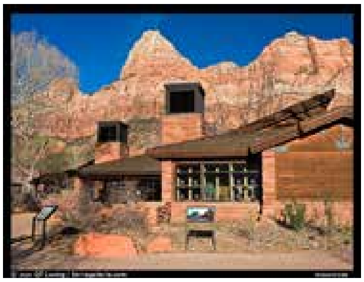
The energy-efficiency strategies incorporated in the design of the bungalows—including passive cooling, daylighting, sensor controls on the lighting and ventilation systems, and relaxed standards for comfort conditions—allow the dog adoption park to use 81% less energy than baseline models.
The efficiency of the passive cooling system made it possible to construct the project without a chiller-based mechanical system. The bungalows are cooled and ventilated in the summer entirely with outside air via indirect evaporative coolers. Air is distributed at 24 inches above the floor and then drawn out of the building at roof level through the wind towers. No air is recirculated to other portions of the building.
The cooling-system design has had the greatest impact on the project's energy use reduction and ensures that the bungalows operate at minimal energy loads during peak demand hours. In the event of a blackout, the cooling system, which is driven by the wind, would continue to operate without interruption. Building sensors monitor both temperature and carbon dioxide levels. These sensors control the intake and exhaust louvers to maintain a healthy and comfortable environment within the bungalows.
Electric lighting, used to maintain minimal Health District standards, is controlled by photocells to ensure that it is not on when daylight is sufficient. Fixtures use high-efficiency fluorescent lamps.
In conjunction with energy-efficiency strategies, the dog adoption park incorporates a photovoltaic system that supplies 28% of the energy load. A wind farm that will provide a further 30% should be completed in 2006. [13]

The Solar Panels:

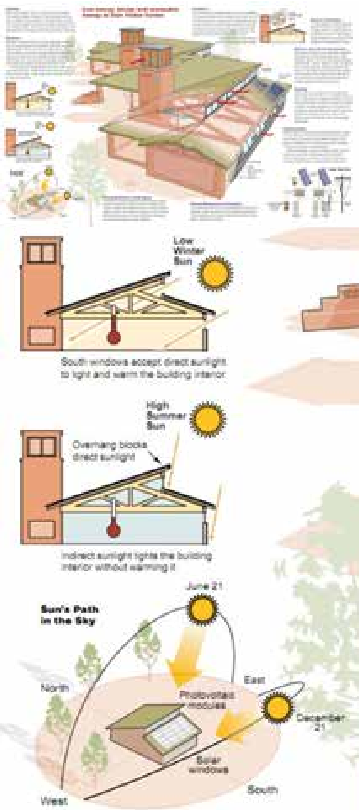
"Designing an energy-efficient building helps reduce pollution from burning fossil fuels, reduce disturbance of natural habitats for the harvesting of resources and minimizes global warming. The project is a leader in the use of renewable energy by relying on photovoltaic panels and wind turbines to produce a portion of the project's energy needs. The building operates more efficiently in comparison to a typical shelter through the use of monitoring and specialized cooling / heating equipment. Windows bringing in natural daylight reduce the center's demand for electricity.
The photovoltaic panels are mounted on canopies that also serve to shade the dog adoption park. The solar PV arrays are oriented on 24-degree angled, (south-facing) independent shade structures. Each structure accommodates eight 160 watt solar modules. The 24 solar shade structures accommodate up to 30 kilowatts DC. This solar installation produces an approximate average of 150 kilowatt-hours AC per day annually. This equates to 28 percent of all electrical energy demands for the Dog Adoption Park. All equipment used on the project, Sunnyboy 6000U Inverters and Sharp ND-167U3 modules, are in accordance with the California Energy Commission "List of Eligible Renewable Equipment". Additionally, the project is in compliance with the Nevada Statewide Energy Conservation Plan and the Governor's Energy Protection Plan." [14]

Brief of strategies:

- **Solar Photovoltaic cells to produce electricity**
- **Natural passive ventilation and using chimney**
- **Thermal mass**
- **Natural lighting by the windows**
- **Perfect orientation for receiving sun radiation in the winter and block it in the summer**
- **Evaporation indirect cooling**
- **Using Sunblind (Sunshade) to make more shadow and receive lower sun direction.**



[Fig-9] Zion National Park Visitors Center



[Fig-10] Zion National Park Visitors Center Passive Architectural Systems

7.2.4 Case **N.4**: Zion National Park Visitors Center in Utah, USA

Credits: National Park Service

"In creating the Zion National Park Visitor Center, the National Park Service (NPS), working with DOE's National Renewable Energy Lab (NREL), has complemented Zion's natural beauty. [Fig-9]

This low-energy, sustainable facility is the entry to a transit- and pedestrian-centered visitor experience, providing park information, interpretation and trip-planning assistance within a resource environment. The visitor center is part of a transportation system that seeks to reduce resource impacts and enhance the visitor experience. Consisting of indoor and outdoor spaces for visitor services, this facility creates a setting to promote and interpret park resources and agency conservation values. It was built in 2002. Several effective energy features were included in this project: daylighting, Trombe walls for passive solar heating, downdraft (cool towers) for natural ventilation cooling, energy-efficient lighting, and advanced building controls. A roof-mounted photovoltaic (PV) system provides electric power. [Fig-10] *This project will save roughly $14,000 and about 10 kW of electric demand per year through these energy-saving measures."*

The Zion National Park Visitor Center is an award-winning example of sustainable design. The Denver Service Center, working with the U.S. Department of Energy's National Renewable Energy Laboratory, created a sustainable building that incorporates the area's natural features and energy-efficient building concepts into an attractive design that saves energy and operating expenses while protecting the environment.

Sustainability:

The facility combines a wide range of basic sustainable designs and technologies. The facility is expecting 80% energy-savings over conventional visitor centers. The park is expected to save $16,000 per year in energy costs. The following is a list of sustainable concepts incorporated into this project:

Energy-Efficient Features:

Trombe wall, Photovoltaic (PV) system, Lighting, Glazing design and selection, Passive down-draft cool tower, Energy-efficient landscaping, Natural ventilation, Thermal mass flooring, Optimized overhangs.

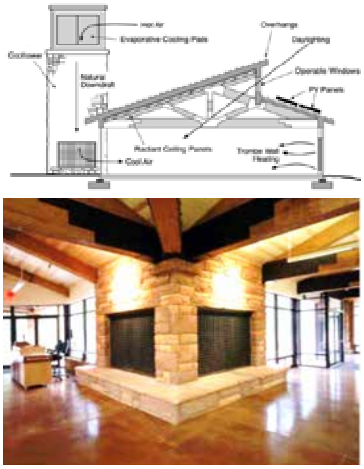
Energy:
A 70% reduction in energy use was met through the design and implementation of natural ventilation, efficient lighting, effective glazing, insulation, passive downdraft cool towers, Trombe walls, photovoltaics, energy-efficient landscaping, and an energy management system. The roof insulation is Structural Insulated Panels (SIP's). The walls are 6-inch steel studs with a spray-in-place foam insulation. The cool tower design was adapted from a technique used to condition outdoor patio spaces. Hot dry air is drawn into evaporative cooling pads at the top of the tower. The air is now denser and falls naturally through the tower into the space. High windows in the building relieve the hot air. 12% of the total energy load is provided by on-site PV, with an additional 10% allowed-for in the building design.

Materials & Resources:
20% of materials, including stone, concrete, and paving, were manufactured within 500 miles (800 km) of the site. Cleared vegetation and pavement were recycled.

Indoor Environment:
Cool towers (which provide over five air changes per hour) and operable windows provide natural ventilation to building occupants. Thermal, ventilation, and lighting systems may be controlled by users. Extensive daylighting was implemented. The building remained unoccupied for two weeks following construction, while commissioning and final punch items were completed. Visual Comfort and The Building Envelope Use skylights and/or clerestories for daylighting. [Fig-11]

[Fig-11] Plan of Ground Floor

Lessons Learned:
Designing the electrical system and installing the conduit for future PV was ideal. When PV was added, it was installed in a few hours. The photovoltaic system and inverter are used for an uninterruptible power supply (UPS) system. A better definition of what loads were to be UPS-powered would have been useful. The UPS system is not guaranteed to provide continuous power. About 5% of the outages have left the building with a brief (less than one second) outage—enough to reset computers. Some small UPS computer backups have been installed for the brief outages. Cool towers have worked as well as direct evaporative coolers except in the enclosed offices, where additional small fans were added. The recommendation is that cool towers be used only in large open spaces. Daylighting levels have been lower than anticipated. This was due to the large number of dark beams in the space and the white stained ceilings (instead of white paint,



[Fig-12] Top: Section;
Bottom: Interior View from the Cool Tower

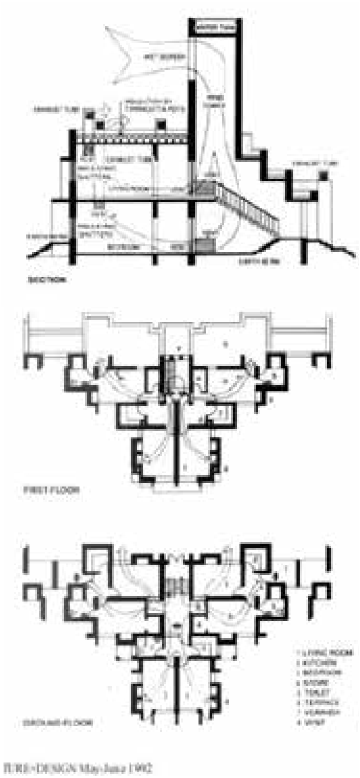
as modeled). In addition, bug screens on the operable windows have affected the daylighting level. The result has been additional operation of artificial lighting. Trombe walls have exceeded operational expectations. However, a design change resulted in two enclosed offices against Trombe walls, and these offices tend to overheat. In large open zones, the Trombe walls are very effective." [15]

Cooling Systems:
"The cooling system functions in two stages. The first stage occurs when the clerestory windows open and natural ventilation cools the space. When natural ventilation is inadequate, the first stage is augmented by using the cool towers to further reduce indoor temperature (second stage). We designed the cool towers to operate on natural convection driven by buoyancy forces and prevailing winds. The cool towers have evaporative cooling pads on all four sides at the top and large operable shutters on all four sides at the bottom. Air is cooled by pumping water over the evaporative cooling pads. This cool, dense air "falls" through the tower and exits through the large openings at the bottom of the towers, as shown in [Fig-12]*. The cool air drawn into the building by the cool towers causes the hot air already inside the space to rise and exit the building through the open clerestory windows. There are no fans in either of the towers. The only energy required for each tower is a 1/3-hp (249-W) pump for water. The building's energy management computer controls the operable clerestory windows, shutter doors, and pumps. The shutter doors on the exterior of the building were intended for cooling the patio area, but they are rarely used because the air entering the patio area dissipated quickly and was not effective. In addition, using the exterior doors degraded the interior performance. Figure 4-16 and Figure 4-17 show the installed towers from the outside and inside the building."* [16]

Brief of Strategies:
- **Trombe wall**
- **Photovoltaic (PV) system**
- **Lighting**
- **Glazing design and selection**
- **Passive down-draft cool tower**
- **Energy-efficient landscaping**
- **Natural ventilation**
- **Evaporation**
- **Thermal mass flooring**
- **Roof and structure insulation**

7.2.5 Case **N.5:** Wind-Tower at Jodhpur University Hostel in Jodhpur, India

"*Jodhpur University Hostel* [Fig-14] *is designed for a hot-dry climate. The main design constraints were a great water scarcity and strong desert winds. This building was put up as part of the research project undertaken by the Centre for Energy Studies, IIT, and Delhi. Although energy conservation was stated as the objective, the design attempted to test and demonstrate suitable methods of providing thermal comfort in the hot, dry climate of Rajasthan. The air being very dry, evaporative cooling in summer can prove to be extremely effective in Jodhpur. The design, therefore, uses a favorable orientation, massive structure and air gap in the roof for insulation, reflective external finishes, deep sunshades and a wind tower for making use of the cool winds. An experimental evaporative cooling system using wires for water distribution also has been installed on the Wind-Tower. The prevailing direction for cool winds in Jodhpur is south-west. Windows apertures are difficult to provide in this orientation as it is least favorable in regards to solar radiation. To overcome this, a Wind-Tower concept was used. The tower faces the wind direction and is located over the staircase, thus minimizing costs. Cool air is provided to each room from this tower and normal windows or smaller shafts (towers) facing the lee of the wind has been provided to distribute the cool air throughout the building.* [Fig-13] *The tower only catches the cool wind from the south-west, avoiding warmer air from other directions. Walls are built of local light colored stone. Large slabs of the same stone have been used for roofing, staircase, partitions and for lintels over windows. Roof insulation is provided by using small inverted terracotta pots over the stone slabs and filling up the intervening spaces with lime concrete. Since very few manufactured materials have been used, this is a low-embodied energy building.*" [17]



[Fig-13] Section and Plans from University of Jodhpur

Brief of Strategies:

- **Thermal mass**
- **Photovoltaic (PV) system**
- **Good orientation for sun radiation**
- **Natural ventilation with Wind-Tower**
- **Low aperture to the summer sun**
- **Local material**
- **Adding water spray and using evaporation effect**
- **Insulation (air gap un top-roof)**
- **Use of chimney for expulsion warmer air**

v

Photo Vinod Gupta

Owner *University of Johpur*
Consultants *Centre of Energy Studies, Indian Institute of Technology, New Delhi*
Contractor *Engineering Cell, University of Jodhpur*
Area *420 sqm*
Cost Rs. *1,600,000*
Date of completion *1987*

[Fig-14] Photo by Vinud Gupta, University of Jodhpur, Architecture+Design May-Jun1992

7.2.6 Case **N.6**: Torrent Research Centre (TRC) Building in Ahmedabad, India


[Fig-15] The Torrent Research Centre in the Hot and Dry Climate of Ahmedabad

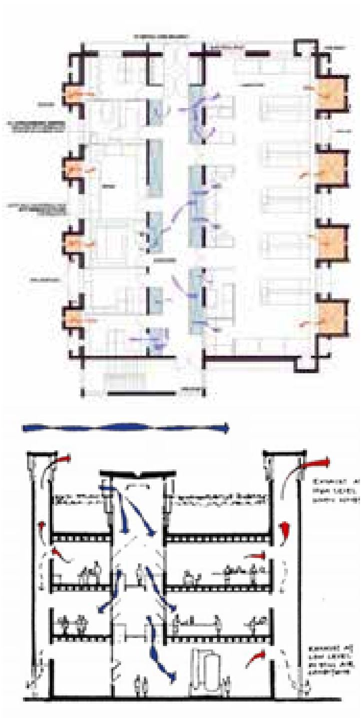
Passive Down Draft Cooling:

"*The Torrent Research Centre in the hot and dry climate of Ahmedabad* [Fig-15] *had adopted the feature of passive down draft cooling to minimize the use of conventional air-conditioning. The design was aimed at integrating spaces requiring highly controlled conditions with those requiring less-controlled conditions while minimizing the presence of dust in the internal environment. Passive cooling is attempted through a system of designated inlets and outlets shafts. The shafts as a consequence of their locations, sizes, heights, and their complex but stimulated and in-depth researched configuration generated the required movement of air in different spaces without using any mechanical or electrical energy*." [18]

"*In keeping with a rich tradition of climate responsive vernacular architecture in India, a number of passive solar and energy efficient non-residential buildings have been developed over the last two decades there.* [19] *These are designed and developed in response to growing concerns for minimizing energy dependence in a context where increased urbanization fuels power demand, over 30% of electricity energy is consumed in commercial and domestic buildings, and air conditioning (AC) accounts for 50% of energy use in modern commercial buildings.* [20] *The Torrent Research Centre Building in Ahmedabad has been widely reported as a unique example for climate responsive design which integrates a passive downdraft evaporative cooling (PDEC) system. A detailed description of the design process, building configuration, environmental control system and thermal performance can be found in an earlier study completed by Baird.* [21] *The building was revisited at the end of 2004 by the authors with the aim of investigating building performance and occupant experience.*

Building Design:

"The TRC complex is comprised of a range of pharmaceutical research facilities and related support services, housed in a group of a dozen or so buildings. This study was focused on the main group of five three-story laboratory buildings and one administrative block radiating from a circular-plan core building. Started in 1994, construction was completed by 2000, and the laboratories have been occupied progressively since the latter part of 1996.

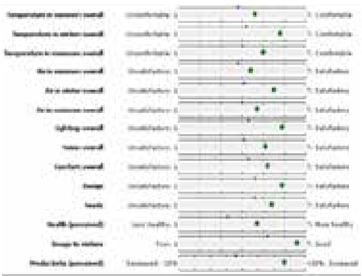


[Fig-16]

Principal architects for the project were the husband and wife team of Nimish Patel and Parul Zaveri, practicing under the name of Abhikram since 1979. From the outset, they resolved that all of their buildings would be able to work during daylight hours using the minimum of electrical energy. In time, this objective evolved into one of the practices. The Board of Torrent Pharmaceuticals Ltd. had decided to make a major investment in research and needed a new facility in order to expand this aspect of their operation. They also proved willing to embrace the Abhikram design philosophy. From the environmental point of view, the intent was to maximize the use of natural light and ventilation, use locally available natural materials, and control the ingress of dust, all of which was a fairly tall order in a climate with three distinct seasons - hot and dry from March to June with temperatures reaching well over 40 ºC, warm and humid from July to September during the monsoon, and cool and dry from October to February, with the 1 % values ranging from +12.8 ºC in the cool season to +41 ºC in the hot season. [22] With the appointment of Abhikram as architects for the center, designing of the first laboratory block commenced in early 1992. A central corridor concept, with working spaces on either side, was developed and the Passive Downdraft Evaporative Cooling (PDEC) method of cooling adopted for the final design in February 1994. In this scheme, the air was supplied via the central corridor and exhausted at the perimeter as indicated on [Fig-16]. While many aspects of environmental design were taken into account, Dr. C. Dutt, Torrent's Director of Research, was quite prepared to take a "wait and see" position on some issues – for example, on the questions of the potential for rain penetration via the ventilation towers, or for lack of air movement in some locations. He was also open to the concept of designing for a threshold temperature (28 – 28.5 ºC), which could be exceeded for a certain number of hours, rather than some absolute value. In this connection, the designers were unstinting in their admiration for him as a critical, but immensely supportive client. [23]
Each laboratory building has a similar 22m by 17m plan, with a 4m wide corridor flanked by 5m deep office spaces and 8m deep laboratory spaces. Two of the five laboratory buildings are air-conditioned, the other three equipped with the PDEC system. The larger main administrative building is located to the north of the laboratories, and a utilities building to the south, with a two level corridor spine linking. The entire six statements of basic design philosophy, viz, conservation of resources is the primary guideline for all the projects. [24] Environmental design consulting services for the typical laboratory block on

this project were provided by the London-based firm of Short + Ford Associates who had carried out pioneering work on natural ventilation systems in Europe. The design served as a prototype for the remaining laboratory buildings and administrative buildings that were developed and detailed by Abhikram with assistance from Solar Agni International, Pondicherry. The design of the more conventional air conditioning systems, for those parts of the building, which required them, was undertaken by engineering consultant Mr. M. Dastur of New Delhi, while the design and complex covers 22,600m2 of floor space, of which around 3,200m2 is air-conditioned. The central plant for this research facility includes two oil fired steam boilers with a capacity of 4T/hr each, two 175cfm air compressors, two 725KVA diesel generator sets, and some 350 tons of refrigeration capacity. Overall control of solar heat gains is achieved by judicious design of the glazing. The fixed windows are shaded externally by horizontal overhangs, and in the vertical plane by the air exhaust towers that project from the façade. The buildings are thermally massive – the reinforced concrete construction framed structure has plastered cavity brick infill walls and hollow concrete blocks filling the roof coffers plastered inside. Vermiculite is used as an insulating material on both roof and walls. External surfaces are white – the walls painted and the roof uses a china mosaic finish.

The critical climatic time of the year is the hot dry season when mid-afternoon outside temperatures regularly reach 40 ºC or more. These are the conditions under which the PDEC system is designed to operate. It does so by piping water through nozzles at a pressure of 50 Pa to produce a fine mist (dubbed the 'microniser' system by Brian Ford) at the top of the three large air intake towers located above the central corridors of each laboratory building. Evaporation of the fine mist serves to cool the air, which then descends slowly through the central corridor space via the openings on each side of the walkway. At each level, sets of hopper windows designed to catch the descending flow, can be used to divert some of this cooled air into the adjacent space. Having passed through the space, the air may then exit via high level glass openings which connect directly to the perimeter exhaust air towers. Nighttime ventilation is also an option during this season. During the warm humid monsoon season when the use of the microniser would be inappropriate, the ceiling fans (introduced to ameliorate the muggy conditions experienced during the first monsoon season) can be brought into operation to provide additional air movement in the offices and laboratories. In the cooler season, the



[Fig-17] Building Use Studies Summary Chart for PDEC Buildings at Torrent Research Centre 100 Respondents – December 2004

operating strategy is designed to control the ventilation, particularly at night, to minimize heat losses. This is done simply by the users adjusting the hopper widows and louver openings in their individual spaces to suit their requirements.Each of the building blocks surveyed was originally designed for occupancy of 25 scientists. With the expansion of activities, increase in staff and overlapping shifts in recent years, some of the buildings currently house as many as 70 to 80 people working at the same time." [25] *All of these strategies create a better comfort situation in this building.* [Fig-17]

Temperatures of 27 ºC on the ground floor and 29 ºC on the first floor with outdoor temperatures at 38 ºC and Majumdar (2001) reports temperatures of 29 – 30 ºC being achieved when outside temperatures reach 43 – 44 ºC. Majumdar also reported temperature fluctuations did not exceed a 4 degree range over any 24-hour period, when temperature fluctuations outdoor were as much as 14 to 17 degrees. One of the early issues noted was a tendency for air to by-pass the top floor. [26] *This latter aspect has resonance with the field studies such as those of Nicol et al (1999), amongst office workers in Pakistan where they were found to be comfortable at temperatures between 20 and 30 ºC, with no cooling apart from fans, and the assertion of Nicol and Humphreys following their extensive work in this field across a number of countries was that "optimal indoor environments in a building are a function of its form, its services (the researchers define this to include controls and building management) and the climate in which it is placed." The performance of the building in the monsoon season was of particular interest in the PDEC buildings.*

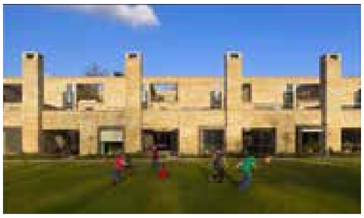
Brief of Strategies:

- The fixed windows are shaded externally by horizontal overhangs
- Vertical plane by the air exhaust towers which project from the façade. The buildings are thermally massive. The reinforced concrete construction framed structure also brick infill walls
- Insulating material on both roof and walls
- External surfaces are white - the walls are painted
- The roof uses a china mosaic finish
- Intake towers are located above the central corridors
- Exhaust-Tower: air may then exit via high level glass openings which connect directly to the perimeter exhaust air towers
- Aperture: hopper windows designed to catch the descending flow
- Mist pump: (add evaporation) fine mist serves to cool the air which then descends slowly through the central corridor

7.2.7 Case **N.7:** Accordia Housing in Cambridge, UK

"*Type: Housing, Architect: Fielden Clegg Bradley (masterplan and lead architect) with Maccreanor Lavington and Alison Brooks Architects, Location: Brooklands Avenue, Cambridge, CB2 8DL*
The site was once the landscaped grounds of Brooklands House, now the local office of English Heritage, which were subsequently developed with temporary government buildings during the Second World War. A re-development brief by Cambridge City Council evolved into a masterplan that gained planning permission in 2003. Construction started immediately and was essentially completed in 2008." [27] [Fig-18]
"*The Accordia project, designed in 2002, is a high quality, high density residential development located within the listed garden grounds of Brooklands House, Cambridge. Within this master plan, designed by Fielden Clegg Bradley, three architectural practices developed 23 innovative housing typologies.* [28] [29] *These comprise a graduated scale and variety of buildings from two stories to five stories organized around a central boulevard. The combination of building types, heights and scales of carefully controlled public and private external spaces provides nuances of character to offset the monotony of the homogeneous scheme. The relationship of dwelling to ground was a major structuring theme of the project. The core of terrace townhouses, designed by Macreanor Lavington Architects, are notable for the high quality of internal and external spaces and exceptional natural lighting achieved within very compact planning dimensions. These*

[Fig-18] Section Accordia Housing, Cambridge



[Fig-19] Accordia Housing, Cambridge, Bricks Material

townhouse types form a continuous four-story terrace of 18 houses. The terrace fronts directly onto a park on one side and a mews lane on the other. The form and language of the townhouses and organization of internal spaces are derived from a reinterpretation of the Georgian townhouse. The plan maximizes the living space and establishes a direct relationship between each primary room and associated external spaces throughout the dwelling. The traditional construction of the first phase development had high levels of insulation, good air tightness and careful detailing to improve sustainable performance rather than a focus on renewable technologies. The townhouses achieved a 30 % improvement in energy performance over 2002 Building regulations. While Accordia creates housing that is high quality and in demand, it would not meet 2016 regulatory requirements and would not be viable as mass market family housing due to its high costs." [30]

Materials:
"The external materials for the housing comprises mostly of bricks selected to match closely the traditional Cambridge Gault clay bricks, with the apartments constructed from Copper and Green Oak.
Many elements of the buildings were fabricated off-site – increasing speed of construction, reducing waste, and improving environmental performance. As they age gracefully, the stock bricks, composite timber and aluminium windows, and all copper and untreated hardwood will require minimal maintenance.

***Chimney**:*
The chimney in summer can have an expulsion effect for warm air, and in winter, it can provide a maximum heat inside the house." [31]

Brief of Strategies:

- **Thermal mass brick**
- **Chimney effect and increase ventilation**
- **Insulated from walls and room**
- **Insulated windows**
- **Saving energy by common wall between building**
- **Thick roof made more insulation**

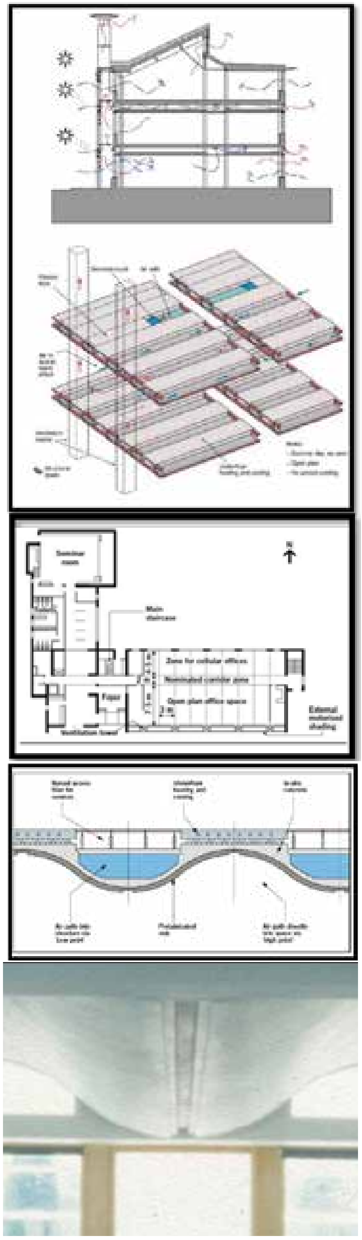
7.2.8 Case **N.8:** The Building Research Establishment (BRE) Office Building [Fig-20]

[Fig-20] The Building Research Establishment (BRE) Office Building

- The Basics Location: Garston, Watford
- Building Type: Office
- Client: Building Research Establishment (BRE)
- Design Team:

Project Manager: Bernard Williams and Associates
Architect: Feilden Clegg Bradley Architects
Services Engineers: Max Fordham and Partners
Structural Engineers: Buro Happold
Quantity Surveyors: Turner and Townsend
Landscape Architects: Nicholas Pearson Associates
Space Planning: DEGW

Background:
The BRE Building project was designed to be an example of new EoF (Energy Efficient Office of the Future) performance specifications. BRE's is an establishment whose job it is to overlook other architectural projects and their progress in energy-efficient and "Green" building design. They used this building as an opportunity to demonstrate all of the characteristics and attributes of what new "Green" building technologies had to offer. Key foci went beyond just energy consumption and looked at embodied building material energy, the building's CO2, SO2, NO, methane, and particulate emissions. The project is located in the core of an old campus on top of old damaged buildings that would be reused in construction.
The new building for BRE (Building Research Establishment) B16, contains office space for 100 staff and 800m^2 of conference facilities. The design focus was made on energy use. This resulted in 30% lower use then current best practices, by making use of the sun, cross ventilation and boring holes to store heat. Further care was taken in choosing materials. The materials of the old building on the site have been reused in the new building for 96%, although not all in the Environmental Building. The building consists of two parts approximately 1300m^2 of offices for about 100 staff and about 800m^2 of seminar facilities. The building is approximately 2,040m^2 of total gross area and 1,470m^2 or net usable area. The stack façade of the building faces almost exactly north south with the main seminar room on the north side of the offices. The offices are 30m X 13.5m with the long axis run-



[Fig-21] Passive Ventilation System in (BRE) Office Building

ning east west, and the west wall connecting to the entrance atrium. The stacks and the solar shading are on the southerly façade of the offices. During the design process, it was decided to follow a two stage tender process, as this would allow a main contractor to be appointed early in the life of the project. They would then be able to advise on buildability issues and assist with the value engineering of the project. This was considered necessary due to the highly integrated approach of architecture, services and structure within the design.

Ventilation & Cooling:

The most distinguishing feature of the building is its five cooling stacks towering over the south side of the building. While they are the most visually prominent feature, they also hint at the building's complex ventilation system that takes advantage of the building's narrow layout for cross-ventilation purposes. The cooling stacks allow for further ventilation on hot, stagnant summer days so the building can always remain well within reasonable temperature levels like that of an air-conditioned building. The curved, hollow, concrete floor slabs also aid in the building's ventilation by drawing air in through the passages in the floor ceiling on hot, windy days. Even further cooling can be managed by circulating water through the passages in the curving slab. This cold water is supplied by a 70-meter-deep borehole, where the temperature is a constant 10° C. This cold water is used in heat exchangers to chill circulatory water. The floor can also then use the water to store "coolness" from the night for the next day. In the wintertime, the water is heated by condensing gas boilers that are 30% more efficient than traditional boilers by recovering heat lost in flue gases. All heating and cooling systems are managed by the Trend building management system (BMS). [Fig-21]

Natural Ventilation: *Natural ventilation is utilized to minimize the use of fans. The use of a novel ceiling slab allows the building to be flexible in terms of space layout without hindering the natural ventilation pathways.*

Night and Ground Water-Cooling*: Air-conditioning is avoided by exposing the ceiling slab. The slab absorbs heat during the day and cools down by ventilation at night. Pipes embedded in the floor can provide additional cooling utilizing groundwater.*

Lighting*: A fully integrated intelligent and efficient lighting system is installed. It compensates automatically for daylight level and occupancy. Each light can be controlled separately.*
Controls*: The operation of the building system is controlled automatically using the latest integrated technology. Occupants also have a high degree of control over their local environment by overriding automatic control of the lights, louvers, windows and heating. In addition, they can manually open mid-level windows.*

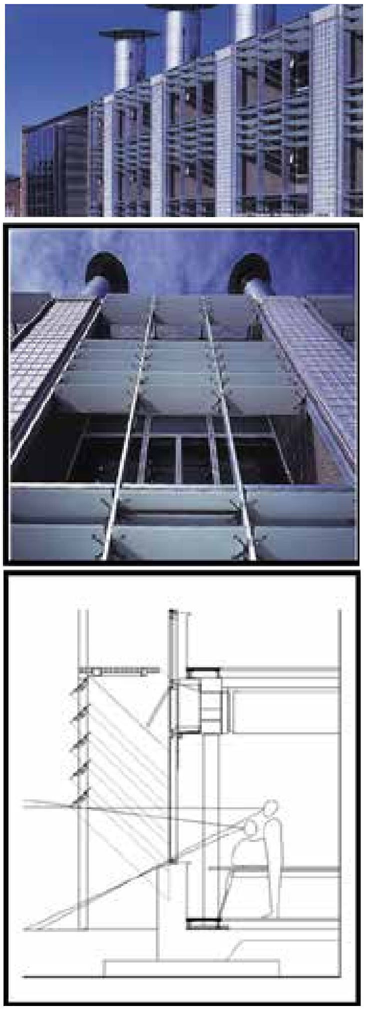
Photovoltaic Array*: The 47m^2 PV provides electricity directly to the building.*

Material Resources Availability*: Demolition Waste of the Former Building has been reused.*

Transportation Systems*: The site is well connected to motorways, although immediate access is through residential areas. There are bus services to both local towns within 500m and a railway station one mile away.*

Water Management*: Low water products are used where appropriate. Borehole water is used in the cooling of the building. The building is connected to the main water supply and sewerage.*

Solar Control and Daylighting:
The building's glazing is optimized by a louvered exterior shading system that is designed to allow maximum daylighting while minimizing glare. The louvers in the shading system have a translucent ceramic coating on their underside to filter direct sunlight as it reflects off it. The louvers change position corresponding to the time of day and season; they are controlled by the automated functions of the BMS, but can be overridden by occupants via a remote control. The louvers are oriented so the views of the occupants are not obstructed while either seated at desks or standing in circulation spaces. [Fig-22]



[Fig-22] Top: View of Chimneys and Louvers; Below: The Louvers in the Shading System have a Translucent Ceramic Coating and Move Automatically

Electrical and Lighting Systems:

Supplementary lighting systems in the building take advantage of TL5 fluorescent lights that consume less energy than traditional tube sand using 1/5 of the mercury. The slim fluorescent light fixtures reflect 40% of their light off the ceiling as diffuse light with the rest, creating a bright workplace (300lux). Power for the lights and other systems is supplemented by a building-integrated photovoltaic array (BIPV); the power from the cells is monitored by the building's computer which lets occupants know what percentage of that power is being used relative to the total power consumption." [32]

Brief of Strategies:

- **Photovoltaic cells to produce electricity**
- **Use of complex thermal mass inside buildings**
- **Use of geo-thermal by cool water that comes from underground**
- **Chimneys for expulsion of hot air**
- **Use of fans to help ventilation**
- **Creation of shade by the louvers which have a translucent ceramic coating on their underside to filter direct sunlight**
- **Use of high technology for the automatic control of louvers movement**
- **Glazing is optimized by a louvered exterior shading system that is designed to allow maximum daylighting while minimizing glare**
- **Integrated intelligent and efficient lighting system**
- **The curved, hollow, concrete floor slabs aid in the building's ventilation by drawing air in through the passages in the floor ceiling on hot and windy days**
- **Cooling can be managed by circulating water through the passages in the curving slab. This cold water is supplied by a 70-meter-deep borehole where the temperature is a constant 10 °C. This cold water is used in heat exchangers to chill circulatory water.**
- **The floor can also then use the water to store "coolness" from the night for the next day**
- **96% of the materials from the old building on the site have been reused for the new building**

7.2.9 Case **N.9**: CH2 Melbourne City Council House 2, Melbourne, Australia

[Fig-23] CH2 Melbourne (Commercial Center) Exhaust Towers

- Architects: Designing
- Location: Melbourne, Australia
- Project Team: Rob Adams (Project Director -City of Melbourne), Mick Pearce (Design Director), Stephen Webb (Design Architect), Chris Thorne (Design Architect), Jean-Claude Bertoni (Project Architect), Vi Vuong (Architect), Aldona Pajdak (Interior Designer)
- Area: 12500 sqm
- Photographs: Dianna Snape, David Hannah
- Consultant Team:
  Hansen Yuncken (Builder), Bonacci Group (Structural / Civil Consultant), Lincolne Scott (Services Consultant), Marshall Day (Acoustics Consultant), Advanced Environmental Concepts (Environmental Consultant), Donald Cant Watts Corke (Quantity Surveyor), City of Melbourne (Landscape Consultant)
- Client: City of Melbourne
- Construction Value: $51M

The City of Melbourne aims to achieve zero emissions for the municipality by 2020. A major contribution to this strategy is the reduction in energy consumption of commercial buildings by 50%. CH2 was piloted in an effort to provide a working example for the local development market. The brief required a building that as far as possible, relied on passive energy systems while producing a premium grade building. [Fig-23]

CH2 employs both literal and metaphorical expressions of environmental intentions in its architectural composition. Nature is used as inspiration for façades that moderate climate, tapered ventilation ducts integrate with daylighting strategies and an evocative undulating concrete floor structure that plays a central role in the building's heating and cooling.

It was the first new commercial office building in Australia to meet and exceed the six-star rating system administered by the Green Building Council of Australia. Equally important to its environmental features is that it provides 100% fresh air to all occupants with one complete air change every half hour.

"The City of Melbourne has set a formidable task for itself – to build a revolutionary new building that harvests sunlight, cool night air, water, wind and rain to create a lasting landmark for one of the world's

most livable cities – through the design of Council House 2. It is affectionately known as CH2 to differentiate it from the currently used Council House building, which is on the adjacent site and has become known as CH1. Both are located on Little Collins Street, right in the heart of Melbourne Central Business District. This striking building will set a new international standard in ecologically sustainable design. It also offers a financially responsible way of meeting the Council's long-term need to house staff and will breathe life into an under-used part of central Melbourne. Construction of CH2 began early in 2004. It made a large step towards meeting its sustainability goals when the Green Building Council of Australia gave the design stage of the building a preliminary 'six star rating' – world leader status – under the new method of comparing the environmental performance of commercial properties, called Green Star. The Green Star rating aims to become a national standard for Australia for green buildings. The tool's comprehensive evaluation process rates the building in relation to its planned management and commissioning, the health and design for well-being of its occupants, accessibility to public transport, water usage, energy consumption, the responsible choice of materials, land use and pollution."

CH2 Building Project:
"CH2 is to be a leading edge example in the procurement of sustainable buildings. The aim is for the building to become a 'lighthouse' design for future central city developments in Melbourne. The approach taken towards sustainability is one that incorporates and draws on social, economic and natural aspects. There were many aims for the building. These were distilled to four key themes established through the initial two-week workshop:

A. People:
Provide a healthy, comfortable, adaptable and stimulating working environment for its primary users (staff) and visitors. The building should be welcoming, accessible and easily navigated, and should provide a positive social environment.

B. Eco Exchange:
The building should respond and interact with its natural environment, in a responsible way, throughout its life cycle. It should do this with: its use of natural resources (e.g. materials, water), efficiency of

form and design, efficiency of construction and operation, the ability for effective reuse, the minimization of waste, the maximization of the use of renewable energy sources during its operation and an overall aim to reduce carbon dioxide emissions to zero.

***C. Green Print**:*
It should also provide at least the same area of green cover as its footprint bearing in mind that this area can be measured vertically as well as horizontally. That is, there should be as many leaves on the building vertically and horizontally as if the land was still under native vegetation. Furthermore, the building should be read as a work of art, including where possible, inspiring works and influences. And finally the building should inspire a new relationship between the city and nature." [33]

***D. Economics**: The idea of 'more from less' – that is, no longer having a focus on minimizing costs but balancing costs with good building construction, optimal operating condition and focusing on people and the environment while maximizing value and benefits throughout its life cycle.*

Description of Process and Technologies:
CH2 has been designed to be a highly energy efficient and sustainable building, with all its systems and spaces forming an interconnected and inter-related whole. Much like a living organism, the building requires all of its limbs and organs to be fully integrated and able to function in unison. We use the term 'biomimicry' to describe this attempt to learn from nature and 'mimic' it into the design. Below is a brief outline of this biological synergy (where relevant to the paper, some of these are elaborated on later in the text):

- ***Leaf structure:** air cleaning and processing, combined with collecting energy and dissipating heat.*
- ***Growth plane**: roof terrace supporting living plants and grasses for the enjoyment of building inhabitants.*
- ***Bronchia:** enclosed duct spaces for delivery of vital gases.*
- ***Root:** network of connections to ground, provision of public services, buttressing to the city plane, sewer mining for non-potable water.*
- ***Stem:** primary core structure and arterial volume providing network of reticulated fluids, gases and nervous system of building for control of cooling, heating and ventilation.*

- ***Epidermis:*** *external layer of skin for protection from the elements.*
- ***Dermis:*** *sub-layer of skin composed of enclosed spaces to filter wind, light and sound.*
- ***Antennae****: vertical mast carrying vegetation and weather monitoring equipment for control of cooling, heating and ventilation.*
- ***Bark:*** *external ventilation module for waste and toilets, with inhabitable external balconies.*
- ***Soft body:*** *the internal activity zone of the building where climate is modified for people.*

The primary influence on the design was the natural termite system. Mick Pearce, MCC design champion, had previously used this concept successfully, in the 'Eastgate' building in Harare (1992 – 1997). He transformed the simple design and system termites build to control the temperature of a mound into the air conditioning systems of the building. The main principle used is very simple: cold air descends, warm air ascends. The physiology of a termite mound is that they build towers that are comparable to human lungs – including a function based on the same principle as gas membrane diffusion. They 'outsource' the function of digestion to fungi that they cultivate in gardens in their mound. These work like our digestive system. Temperature and humidity control is essential for their survival and the survival of the fungi. They also mine water for drinking and cooling. Thus, termites have evolved an architecture that harvests solar and wind energy, water and food through fungi using symbiosis.
Other elements of the thermally efficient design concept for CH2 were the use of thermal mass, ventilation stacks and water for cooling through chilled ceiling panels, beams – the water cooled by the coolth stored in phase change material tanks. We briefly outline these elements as follows: thermal mass. The vaulted 'wavy' ceilings are made from pre-cast concrete and therefore have high thermal mass that, as it is in contact with the indoor air, helps the building spaces to remain cooler during the day as the thermal mass absorbs some of the excess heat. This heat is then released during night purging.

Ventilation Stacks*:*
Ventilation stacks have been designed to the north and south of the building. To the north, the stacks have been designed to be dark, increasing in size up the building to support air movement, while reducing windows sizes. That is, the largest windows are at street level where there is the least natural light, gradually reducing window siz-

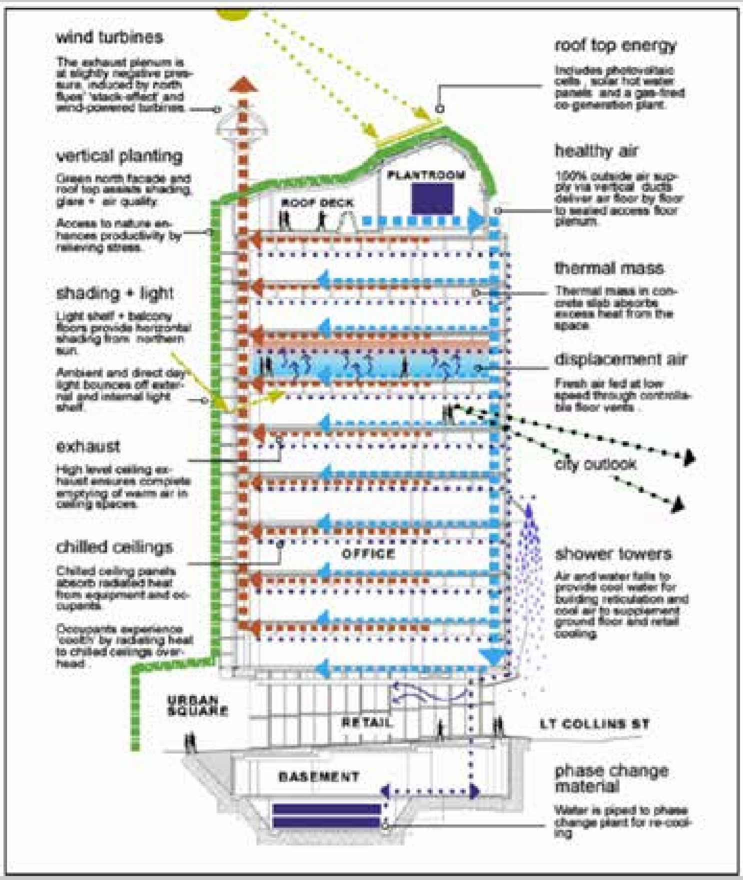
es until at the top, there is the most natural light and therefore the smallest windows.

Chilled Beams and Ceiling Panels:
Cold water will be used to remove most of the unwanted heat from the building. The panels and beams simply run chilled water through them – the water absorbs the heat from the air, cooling it and taking the heat away.

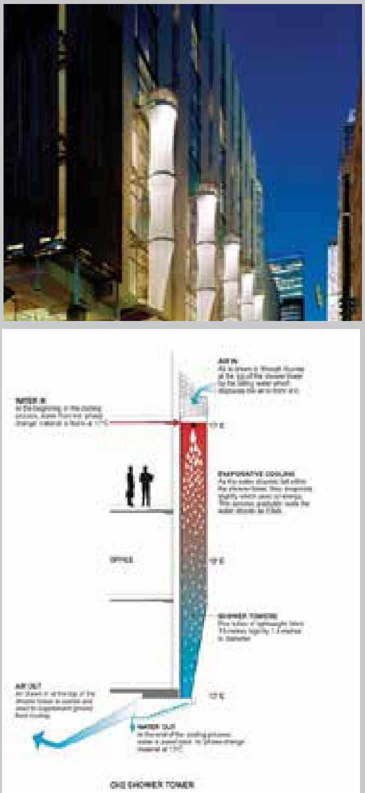
Phase Change Material:
The design includes the use of a phase change material to cool the water for the chilled beams and panels. This is often referred to as the 'battery' of the building – storing the cool generated from the shower towers and chillers to be used when needed. Thus it will efficiently help to keep the water circulating through the chilled panels and beams at the desired temperature.
Shower Towers:
The final feature of the design that aids in the control of the indoor air environment is the shower towers on the southern façade. Outside air is drawn in from 17 meters or more above street level and channeled into the shower towers on the south side of CH2. The towers are made from tubes of lightweight fabric 1.4 meters in diameter. As the air falls within the shower tower, it is cooled by evaporation from the shower of water. The cool air is supplied to the retail spaces and the cool water is supplied to the phase change material 'battery' where the 'coolth' is stored for the rest of the building when required. [Fig-24]
The brief descriptions above inform us that the construction materials and elements used are not unusual. On the contrary, these are common materials but put to use in an innovative way. Furthermore, materials were selected using a review process developed by CSIRO and product guidelines such as Eco Specifier were used. [Fig-25]
The CH2 proposal therefore, had to meet these criteria as well as those set up in response to environmental strategies, including the requirements to meet at least a 5-star energy level and the energy targets set out under the Energy Management Strategy and accompanying Energy Policy to guide corporate change. Specific targets being: 20% reduction of energy consumed in Council buildings by 2005 (based on 1996 levels), and 5% Increase in the use of renewable energy by 2005 and 10% increase by 2010." [34]

Brief of Strategies:

- **Wind Turbines to exhaust the warm air**
- **Vertical vegetation**
- **Hierarchy for windows larger on lower levels and shorter on top**
- **Shading by covering the face with louvers**
- **Evaporation by shower-tower**
- **Chilled ceiling**
- **Thermal mass**
- **Photovoltaic cells**
- **Filtering the pollution with mist**



[Fig-24] Diagram of Passive Cooling Technology in CH2 Melbourne



[Fig-25] Left: Shower Tower; Right: Diagram of Shower Tower Cooling

7.2.10 Case **N.10**: Hai D3 / Ibda Design in Dubai, UAE

Architects: Ibda Design
- Location: Dubai – United Arab Emirates
- Architects in Charge: Wael Al Awar and Kenichi Teramoto
- Design Team: Yuka Takeuchi, Sho Ikeya, Takeshi Harikai, Takuma Fujisaki, Makoto Udagawa,
- Area: 1877.0 sqm
- Project Year: 2015
- Urban Planner Cultural Engineering: (Rashid bin Shabib)
- Swing Design: Case Design
- Lighting: PSLAB
- Contractor: AMBB Interiors

"The development was designed as a neighborhood, bringing into fact that the masterplan of the whole Dubai Design District was meant to develop a community of artists within the region. Inspired with the efficiency of the traditional Arabic neighborhood planning, the project's layout was designed to accommodate open spaces, which are further developed into landscaped "pockets" that serve as courtyards for each of the buildings in the complex. These courtyards not only complement the industrial nature of the architecture, but also promote activity, and consequently, vibrancy to the entirety of the site. [Fig-26]
These buildings are formed with the use of recycled 40-foot shipping containers that were crafted with the careful consideration to preserve its raw, industrial form. The use of these shipping containers allows an expeditious building and dismantling process that can be helpful to refabricating the architecture, if deemed necessary. Six different layouts of stacking were implemented, which was formed to directly respond to the space program of the site. Art galleries, a workshop, a library, retail spaces, as well as a cafe and prayer rooms were introduced in the buildings, which were arranged according to the facility's use. Annex buildings were also introduced in the project, bringing in 20-foot service containers for toilets and storage, as well as an entrance piece that not only welcomes people to the district, but also serves as a multi-function space which artists can use to host movie screenings, gatherings, or outdoor workshops.

[Fig-26] Hai D3, Dubai

[Fig-27] Use of Wind-Tower for Public Spaces

Sustainability was considered throughout the creation of 'hai d3' in regards to initiatives already active in the region. All structures are passively cooled by 'Wind-Towers' that catch high draft wind and funnel it towards the on-site courtyards. Passive lighting was also employed as full-height windows and high sidelights that exploit the abundant sunlight of Dubai. [35] [Fig-27]

Brief of Strategies:

- **Use of natural ventilation for public spaces**
- **Insulation boxes and windows**
- **Shading by covering windows**
- **Vegetation**

7.2.11 Case **N.11**: Courtesy of Gensler – Connie Zhou in Pittsburgh, USA

- Architect: Gensler
- Location: 300 Fifth Ave, Pittsburgh, PA 15222, USA
- Architect in Charge: Doug Gensler
- Architectural Design Director: Hao Ko
- Project Director: Lisa Adkins
- Area: 800000.0 ft2
- Project Year: 2015
- Manufacturers:
  Toto, LCN, Vitro®, Armstrong Ceilings, Tuohy, Semco, Six-inch, Herman Miller, BASWA acoustic, Hunter Douglas Architectural, Haworth, Interface, Designtex, Blumcraft, 9Wood, Von Duprin, Knoll, Poltrona Frau, Aquacell, C.R. Laurence + 41

When Gary Saulson, PNC's Director of Corporate Real Estate, came to Gensler's Chicago office in 2011 for The Tower at PNC Plaza project kick-off, he challenged the team with an audacious goal: design the greenest sky-rise in the world. Months earlier, the design team had traveled to Europe and Canada to study best-in-class high-performance buildings. Seeing first-hand the focus on the quality of the built environment with respect to performance, and the ubiquity of building technologies such as double-skin façades and passive radiant systems emboldened our resolve to rethink how green office buildings could be designed back at home.

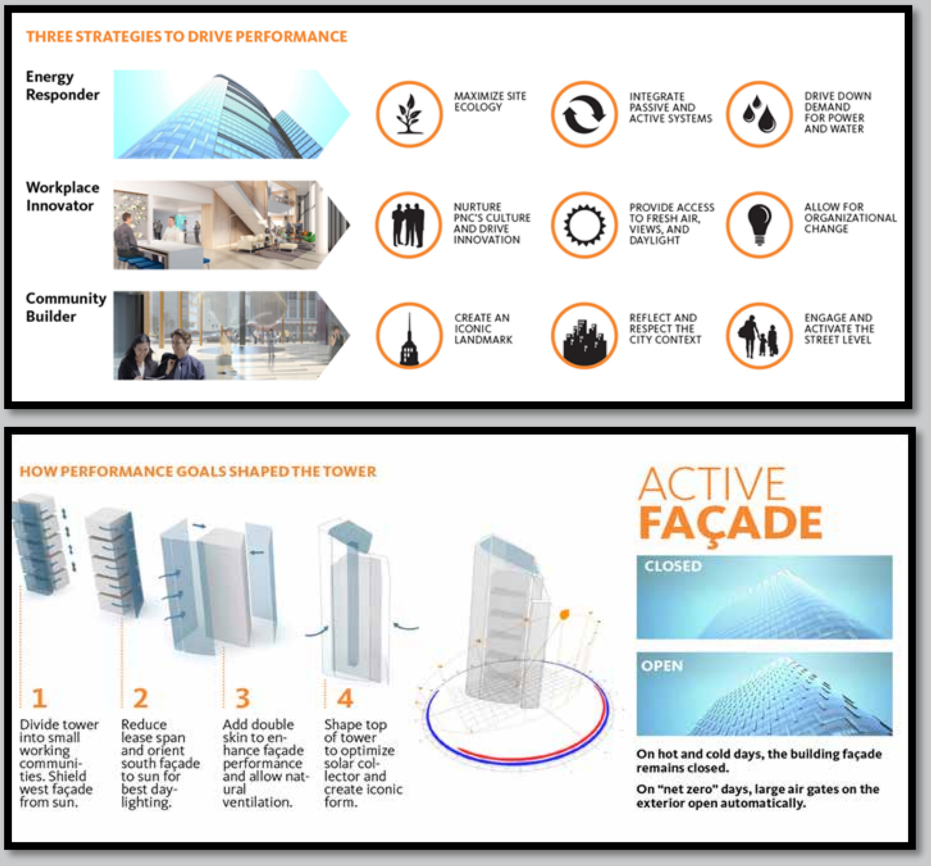
Diagram:
*First and foremost, we realized we needed to define what greenest sky-rise meant. At the time, the term **"green"** was almost uniquely focused on LEED standards and energy conservation. This meant that buildings fell into two categories: buildings that were very small and kept their energy footprint similarly small, or more traditional buildings that were large but had a lot of bolt-on technologies to reduce carbon emissions. Neither fit our vision of what The Tower at PNC Plaza could or should be.*
*Instead, we crafted a vision for the project that holistically addressed user experience, health and wellness, **energy savings**, workplace innovation, and responsible community stewardship. Inspired by the newly introduced Tesla car, which had redefined its industry by uniting driver experience and environmentally friendly performance*

(one could go from zero to sixty in under four seconds and have a zero carbon footprint in a car that also looked great), our team sought to design something that would exemplify the best of contemporary architecture, facilitate a transformational employee experience, and set new benchmarks for saving energy and water.
To do this, we put the user experience at the forefront of the design process. Our snapshot of the ideal workplace was that of an employee working on a park bench on a sunny afternoon, connected online via a tablet, enjoying the sunlight and abundance of fresh air. Most building designs seek to create optimized interior environments by solely focusing on importing as much daylight as possible. We wanted to go one step further by developing a passive natural ventilation strategy that would bring fresh air into the building, giving workers a true feeling of being outdoors and connected to nature. [36]

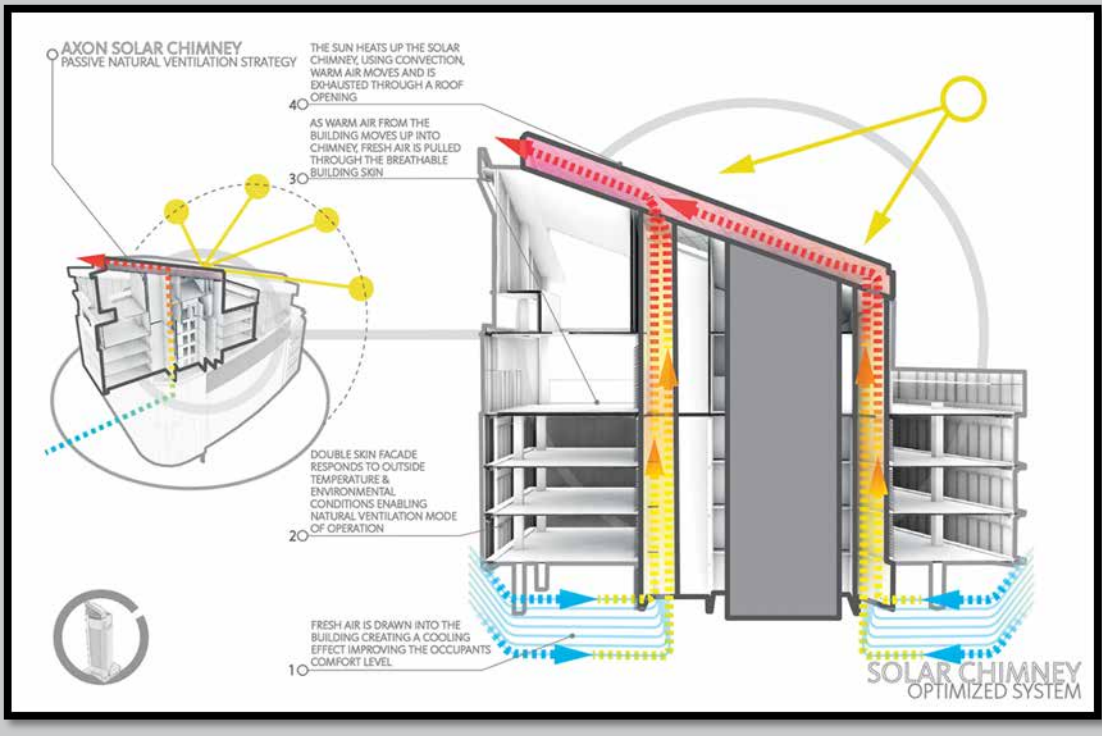
Courtesy of Gensler – Connie Zhou had three main strategies to present a high performance:
A. Energy Responder*: Use active and passive systems for cooling and warming.*
B. Workplace Inventor*: Innovation, provide access to fresh air views and daylight.*
C. Community Builder*: Reflect to city context, engage and activate the street level, create an iconic landmark*. [Fig-28]

Form and Orientation:
The building oriented in the best way to receive natural light and the tower divided in small working communities. Reduce lease span and orient south-faced to sun for best daylight; add double skin to enhance façade performance and receive natural ventilation; orient the shape on top of the tower to receive higher radiation as a solar-chimney. [Fig-28]

Solar-Chimney:
In the highest part of the building, we can find a solar-chimney made by the materials that have a high absorbing capacity of sun radiation. In this way, the air inside becomes warm and moves towards higher levels and an expulsion effect is created, and leads lower fresh air to higher levels throug two vertical ducts, which are connected to the solar-chimney. The double skin façade creates a good insulation for the interior parts. [Fig-29]



[Fig-28] Shape Performance



[Fig-29]

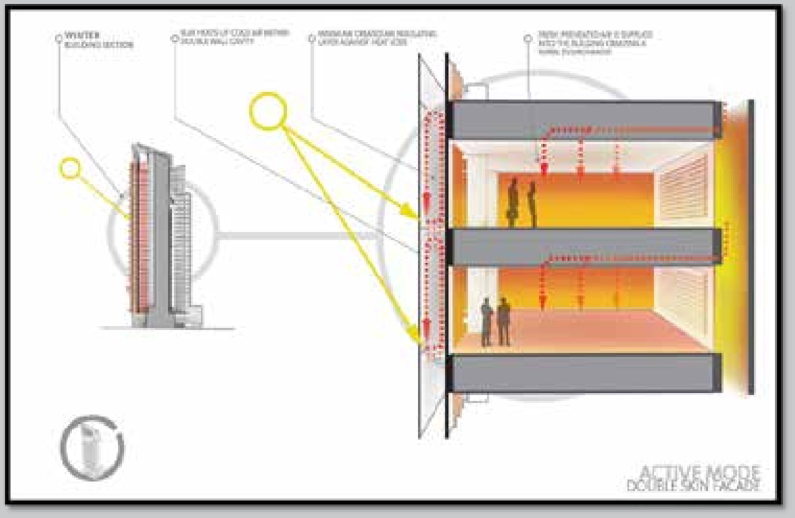
In Winter: *By closing the exterior façade, the air which is blocked between the layers, becomes warm and creates an insulation from the outside cold temperature. By closing the solar-chimney aperture to the outside, the warm air could enter inside the building. [Fig-30]*

In Summer: *By opening the exterior façade, air could have circulation and by opening the solar-chimney on top, it could lead cool air to the vertical towers to higher levels, and then lead it into the building*. [Fig-31]

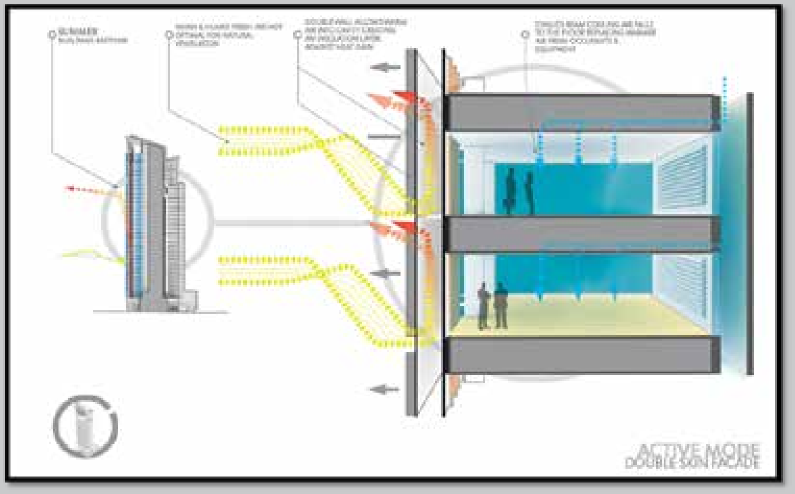
In Fall and Spring: *By opening two façade layers and the chimney aperture, it would create the maximum natural ventilation*.
[Fig-32]

Brief of Strategies:

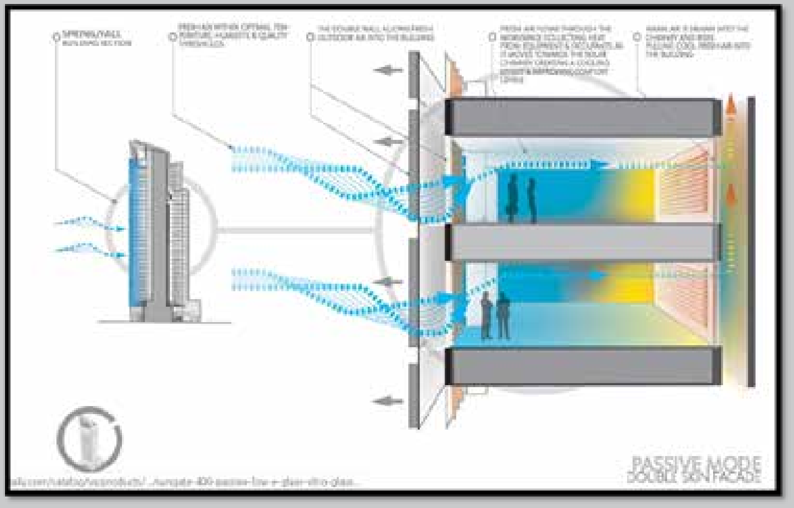
- **Thermal mass in structure**
- **Double façade and insolation**
- **Shading by louvers**
- **Solar-chimney**
- **Natural ventilation**
- **Correct orientation**



[Fig-30] Winter



[Fig-31] Summer



[Fig-32] Fall and Spring

7.3 Conclusion

After analyzing all of these case studies, we can see that this new technology helped to produce high performance buildings. Mostly, they used technology to improve and optimize the performance of using natural resources and passive cooling systems.
Without any doubt, the new invention and science development gives architects new potential to improve the traditional and vernacular architecture.
When we compare the contemporary passive cooling with vernacular and traditional passive cooling, a potential for a new contemporary period arises. We can divide these new potentials into five categories:
A. Digital Technology and Software: (Controllers)

- **Digital technology and software engineering:** helps architecture to create a smart building that could open and close or change the direction of the windows and other apertures. For louvers digital system, it could order to move or rotate to prevent the direct sun radiation or in reverse, in winter, it could rotate and move according to the sun position in the sky to receive the highest level of radiation.
- **Provide over consumption**: Through the thermal sensors, it could control the building temperature in a fix misuser, and not let the energy consume more than our needs.
- **Control mechanical systems that work in the passive cooling processes:** It could control the water spraying in the air and control the humidity.
- **Modeling software:** Different software like Fluent and other NfC simulators help us to analyze the building behavior in different situations of ventilation or by the Ecotect, we can analyze the radiation and find the best orientation for architectural projects.

B. Innovation in the World of Materials: (Materials and Architecture Products)

- **Insulations**: Everyday new typologies of insulation with different forms are present, with material and characteristics that could help the performance of the maintenance of heat or cool air inside buildings.
- **Windows and glass:** New windows could also control the entrance of the sun rays or could perfectly insulate or have the possibility to open or close in different ways.
- **New thermal mass materials and colors:** New material with high absorbing capacity and color that could absorb or reflect the main part of sun radiation.
- **Industry and capacity to produce any kind of architectural elements:** Like different types of louvers, Wind-Towers, or evaporators.
- **Electric Ventilator (Fan):** In many contemporary passive cooling projects, fans have been used as an auxiliary engine to increase the ventilation effect.

C. Science and New Instruments:

- **Measurement of instruments:** All these instruments help us to collect necessary information.
- **Data:** Many different public organizations now can analyze and control different data like meteoric information for any city in the world by the synoptic stations or geology information.
- **Science of calculation and analysis of different data:** Now we can calculate the misuse of the humidity temperature and airflow inside buildings and using all this information, we can try to work on the architectural projects.

D. New Passive Cooling Methods

- **Trombe-Wall:** Trombe walls work on the basic greenhouse principle that heat from the sun in the form of near-visible shorter-wavelength higher-energy ultraviolet radiation passes through glass largely unimpeded.
- **Solar-Chimney or (thermal chimney):** A way of improving the natural ventilation of buildings by using convection of air heated by passive solar energy. A simple description of a solar chimney is that of a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building.

Geo-Thermal Technology: A geothermal heat pump or ground source heat pump (GSHP) is a central heating and/or cooling system that transfers heat to or from the ground.

- **New Thermal Mass:** In building design, thermal mass is a property of the mass of a building, which enables it to store heat, providing "inertia" against temperature fluctuations.
- **Vertical Garden:** Could help with the evaporation or increase shading and reflect sun radiation.
- **Hybrid Strategies:** When we use different typologies of passive strategies together to create a better comfort condition.

E. Produce Electricity:

- **Photovoltaic Cells:** Can produce electricity by sun radiation.

- **Wind Turbines:** Can produce wind by mechanical turbines.

What are the main defects and benefits of contemporary and ancient passive cooling strategies?

Ancient Passive Cooling Strategies:

- **Main Benefit:** It works without use of electricity, uses 100% natural resources and architecture techniques, and it can be used everywhere.
- **Main Defects:** It is hard to control all the parameters.
- Contemporary Passive Cooling Strategies:
- **Main Benefit:** It is possible to control and program different strategies together and give the architect more possibility to design.
- **Main Defects**: With little projects, if the costs of using high technology and new materials are very high, then it is not convenient. It is also difficult to use in developing countries.

7.4 End Notes

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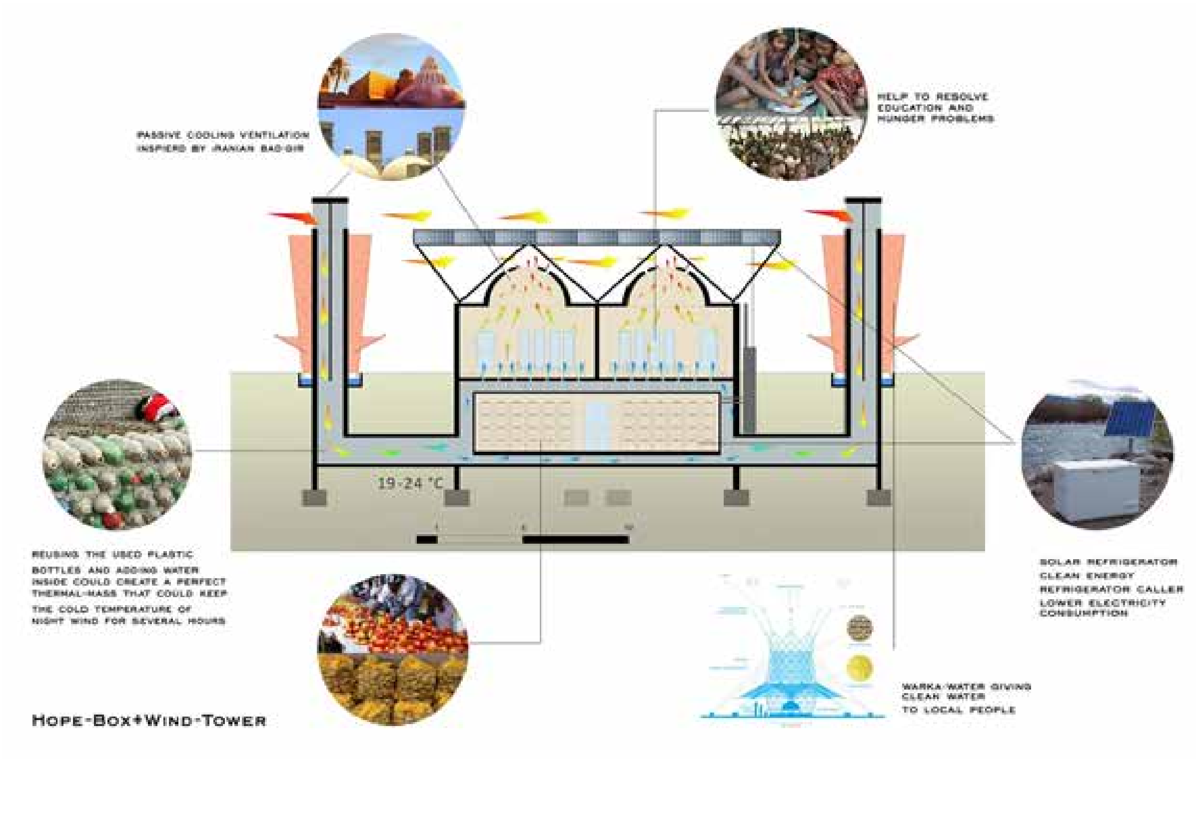
PART III

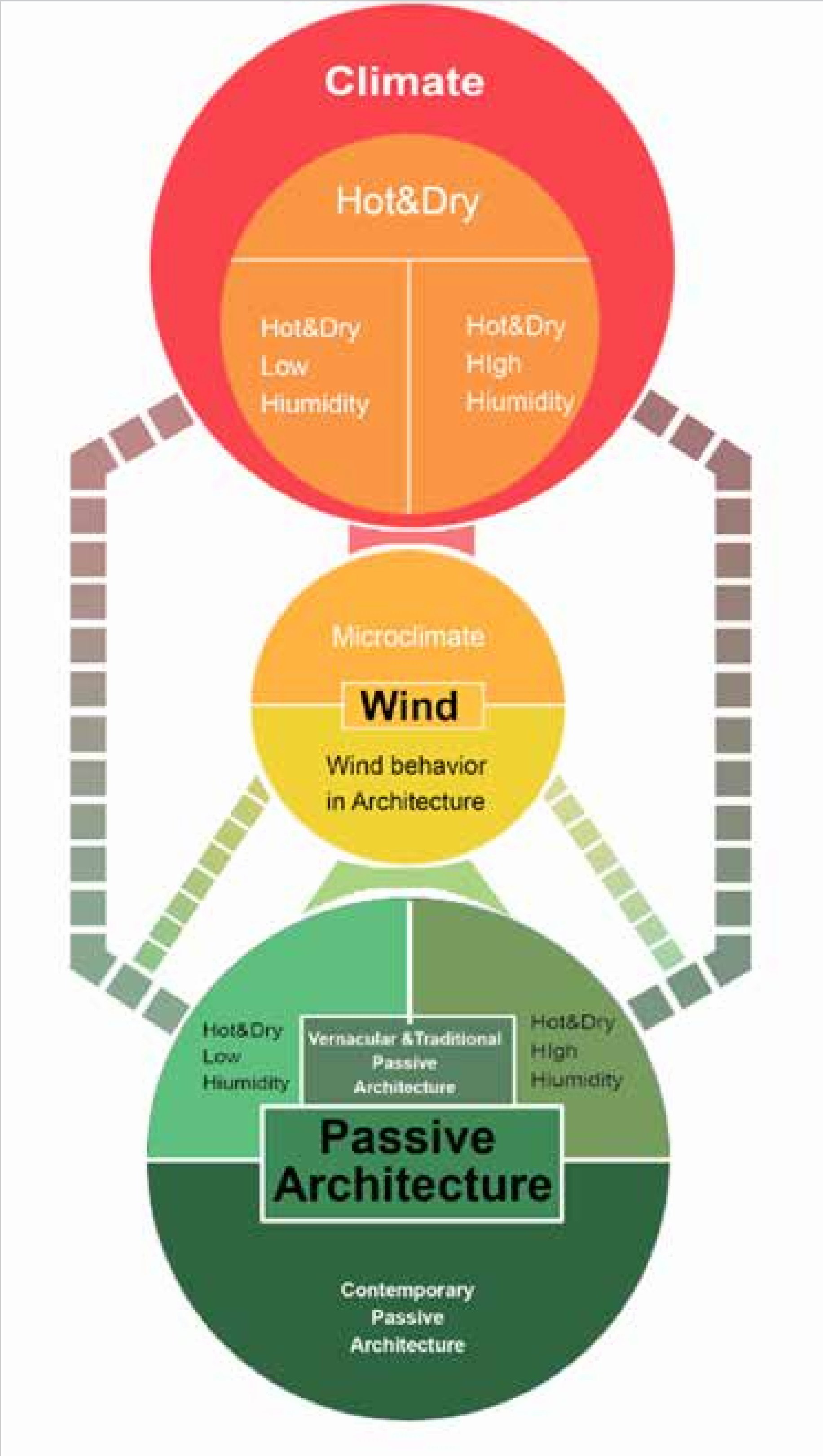
Conclusion and Project

CHAPTER 8 Practical Conclusion: Construction of Sustainable Architectural Project for Schools and Food Conservation in Developing Hot Climate Countries


PASSIVE COOLING VENTILATION
INSPIERD BY IRANIAN BAD-GIR
HELP TO RESOLVE
EDUCATION AND
HUNGER PROBLEMS
19-24 °C
REUSING THE USED PLASTIC
BOTTLES AND ADDING WATER
INSIDE COULD CREATE A PERFECT
THERMAL-MASS THAT COULD KEEP
THE COLD TEMPERATURE OF
NIGHT WIND FOR SEVERAL HOURS
SOLAR REFRIGERATOR
CLEAN ENERGY
REFRIGERATOR CALLER
LOWER ELECTRICITY
CONSUMPTION
WARKA-WATER GIVING
CLEAN WATER
TO LOCAL PEOPLE
HOPE-BOX+WIND-TOWER

8.1 Introduction

In previous chapters, we first studied hot climates, wind behavior and their characteristics. We then researched thermal comfort and passive architecture methods. Furthermore, we described passive cooling and natural ventilation techniques in the vernacular traditional architecture of Middle Eastern countries, specifically in Iran. After that, we began to investigate two types of case studies: the first one focused on Iranian Wind-Towers and Wind-Boxes, in order to thoroughly explore their cooling strategies in collaboration with evaporation, thermal mass and lower temperatures of underground floors. In the second group of case studies, the goal was to find the differences between ancient and contemporary passive cooling architecture, and also to uncover what new possibilities exist for architects. In addition, we want to find the major benefits and disadvantages of passive architecture today. This study shows that a direct relationship exists between vernacular passive architecture strategies in its context (hot climate). [Fig-1]
In Chapter II, we examined some of the world's most largescale social problems: poverty and hunger in developing countries with hot climates. We found a very close connection between hunger and poverty in these countries, and explained the three main problems facing these populations. We now need to find a solution to help them using passive architecture, which will utilize the minimum amount of technology (like passive vernacular architecture in the Middle East).



[Fig-1] Diagram of the Relationship between Passive Architecture, Climate and Wind (Copyright: Amir Imani)

8.2 Objectives

After gathering all this theoretical research and scientific results regarding hot climates and traditional and contemporary passive cooling strategies through ventilation, this chapter will present a functional and practical output to these studies, using passive traditional, vernacular and low cost contemporary architecture to design a small-sized school consisting of two classrooms and an underground refrigerator that works with photovoltaic panels. In this way, the projects will be independent from the use of local electricity.

8.3 Process of Design (Questions)

The process of design in this project was made through use of mono-dialoging by architect (Amir Imani). A logical answer was found based on all the studies and research, which was conducted in this dissertation by using natural ventilation and passive cooling systems and a step by step approach to arrive at this final product.

8.3.1 Question N.1: Where are the current buildings located that have used contemporary passive cooling strategies in its architecture?

Most of the buildings that were built in a contemporary way are located in developed countries like: Australia, USA, UAE, and UK; and they all used passive cooling strategies using high technologies, software and advanced materials.

8.3.2 Question N.2: How we can apply passive cooling architecture in developing countries with hot climates?

It is common knowledge that using high-technology is very expensive, and in many parts of these countries, there is little or no access to high technology and electricity. Thus, the solution is to use vernacular traditional cooling strategies. We could also use low cost contemporary passive cooling or photovoltaic cells to provide them with clean electricity.

8.3.3 Question N.3: How could passive architecture cause a significant influence on human life in developing hot climate countries?

We find that the three main problems in these countries derive from: [Fig-2]

- Low Income
- Low Education
- Low Levels of Health, Food and Clean Water

We should see how passive architecture could give a practical answer to these three problems and create a better quality of life for these populations.

8.3.3.1 Passive Cooling Architecture and Low Income Problems

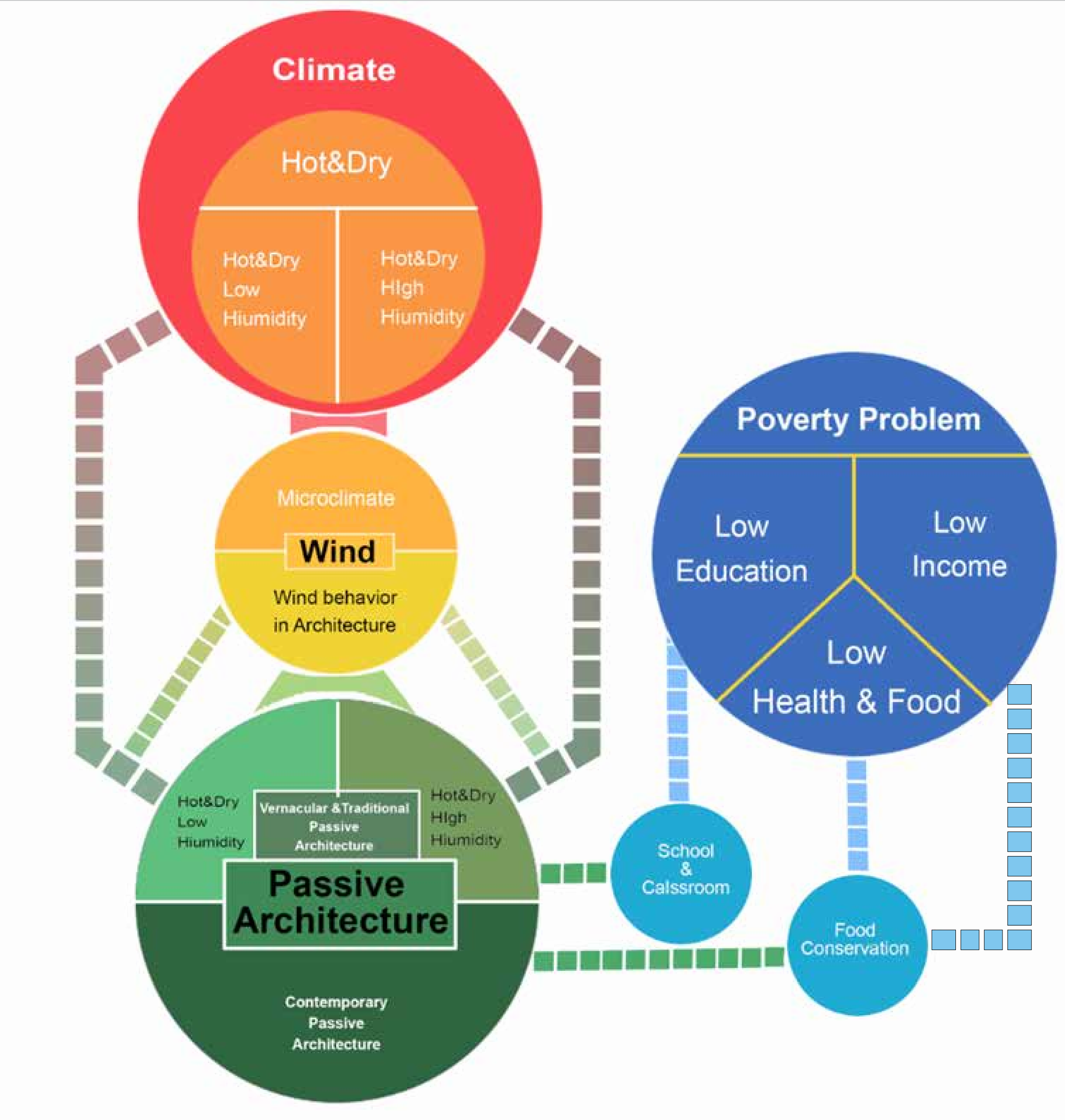
Passive cooling and architecture should create a connection with vernacular local architecture and culture, in order to create a better type of architecture and thermal comfort in these areas. International humanitarian organizations could play a very important role in teaching passive cooling architecture methods to the local communities in these low income countries and also give them some facilities through these goals.
Making a storage facility for farm products could help them to resolve the problem of short-term conservation of foods and sell the farm products in time and in turn, earn more money.

8.3.3.2 Passive Cooling Architecture and Low Levels of Education

According to the international organizations and national school building programs in hot climate developing countries, we can create schools that are passively cooled and also have better thermal conditions and natural lighting inside the classrooms. In this way, we could assist students and teachers to have higher proficiency and performance levels and improved health conditions.

8.3.3.3 Passive Cooling Architecture and Low Levels of Health, Food and Water

Passive architecture could help people to create a better thermal comfort in their private and public spaces, and consequently, cause the human body to have lower levels of perspiration, and in turn and a lower desire for water to dehydrate. Thermal comfort could also have a direct influence on the human health condition, especially for the elderly and for people in the lowest income brackets who live in hot climates.
We could present some passive projects for conservation of farm products to secure their freshness for a longer period of time. In this way, we could help them to provide local products for a longer period. For example: if one tomato supposed to expire in ten days, by conservation, it could take a longer time (like 25 days or more).



[Fig-2] Diagram of the Relationship of Passive Architecture, Climate and Wind and Poverty Problems (Copyright: Amir Imani)

8.3.4 Question N.4: According the above questions and answers, what are the main buildings which are essential for people's lives who live in hot climate developing countries?

The answer is something that could facilitate in the reduction of poverty, and improve food security and access to education.

8.3.4.1. Why School for Children?

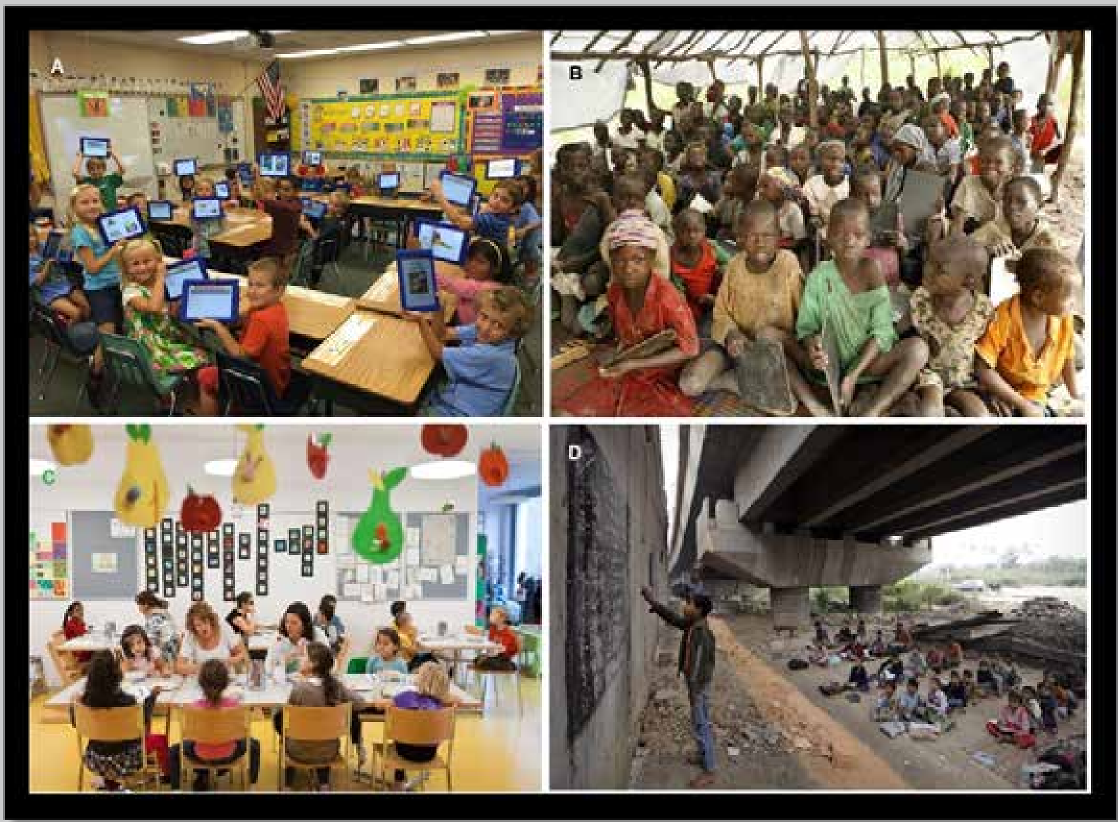
Schools play a very important role in resolving one of the main problems facing the developing world – education. These countries have a real need to build as many schools as possible. School is the place where children spend almost seven hours a day. Good conditions in school could make children more eager to attend, and learn science, math, a different language, etc. It fosters an environment where children increase their general knowledge, and cultivate their talents and social relationships. Passive architecture creates a better thermal comfort, and better thermal comfort has a direct connection to children's brain functioning. Therefore, it can create an overall stronger future in any country, as education is a fundamental service that must be offered to all of its children. [Fig-3]

8.3.4.2 Why Refrigerators and Freezers for Farmers?

In hot climate countries, one of the main problems facing their agriculture industry after lack of access to water, is a lack of conservation. Farmers should sell their products in a short period of time. This creates three additional problems:

Market: Farm products are sold at lower prices: because there are many other farmers that want to sell the same products at the same time (and thus economic market forces cause selling prices to drop)

- **Food Security Period:** According to the research that was done in Chapter II, high temperatures will increase the bacterial levels in foods, thereby shortening the period to expiration. When they are conserved in refrigerators, many products can last longer in a favorable condition. [Fig-4]



[Fig-3] A: Classroom in USA;
B: Classroom in Africa;
C: Classroom in Switzerland;
D: Classroom Under a Bridge in Delhi, India

HOW LONG DOES IT TAKE FOR FOOD TO GO BAD?

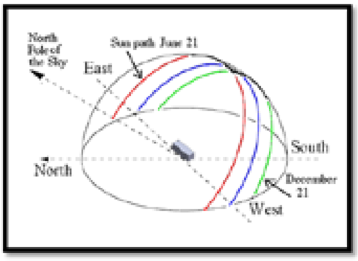
[illegible]	PANTRY	REFRIGERATOR	FREEZER
[illegible]	1-3 DAYS	3-4 WEEKS	10-12 MONTHS
[illegible]	2-5 DAYS	5-7 DAYS	2-3 MONTHS
[illegible]	4-7 DAYS	3-5 DAYS	3-6 MONTHS
[illegible]	1 WEEK	2-3 WEEKS	3-4 MONTHS
[illegible]		3-5 DAYS	12-18 MONTHS
[illegible]		3-4 WEEKS	12-18 MONTHS
[illegible]		3-5 DAYS	10-12 MONTHS
[illegible]	5-7 DAYS		10-12 MONTHS
[illegible]	1-5 DAYS	2-3 DAYS	2 MONTHS
[illegible]		1-2 DAYS	3-4 MONTHS
[illegible]		1-2 DAYS	9 MONTHS
[illegible]		1-2 DAYS	2-3 MONTHS
[illegible]		3-5 WEEKS	1 YEAR
[illegible]		3-5 DAYS	1-2 MONTHS
[illegible]	5-7 DAYS	1-2 WEEKS	3 MONTHS
[illegible]	1-2 WEEKS		
[illegible]	1-2 DAYS	7 DAYS	2-4 MONTHS
[illegible]			1-2 MONTHS
[illegible]		1 DAY	3-4 MONTHS
[illegible]	3 YEARS +	3-5 DAYS	4-6 MONTHS

MOLD GUIDE

[Fig-4] Left: Competitive Market for the Same Farm Products; Right: Food, Expiration and Conservation Period

8.3.5 Question N.5: What kind of low-cost passive cooling strategies could have a good influence on schools and food conservation?

Orientation: Finding the best orientation towards the sun, will help to have natural light in summer and winter, and receive lower sun radiation during hot months. [Fig-5]



[Fig-5]

- **Color and Painting:** The color of a building should reflect the sun radiation as much as possible so white and light colors are more appropriate.

- **Thermal Mass:** Using simple and local thermal mass products could be helpful to conserve the nighttime cool temperatures and receive it back during the daytime. We can use low-cost and local material like: Adobe, Clay, Brick, Concrete, and Local Stone with high thermal storages of water. [Fig-6]

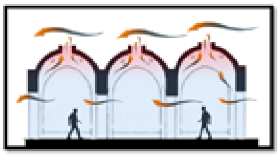
[Fig-6] Thermal Mass and local Low-Cost Material

- **Natural Ventilation:**

  A)Wind-Tower: In order to have natural ventilation after studying the local wind behavior and its microclimate, we can decide the typology of Wind-Catchers. If the predominant wind comes from one direction, we should use a Wind-Tower with one opening, otherwise ones with four or more openings. [Fig-7]

[Fig-7] Three Simple Typologies of Wind-Towers That Could Be Used in Different Conditions

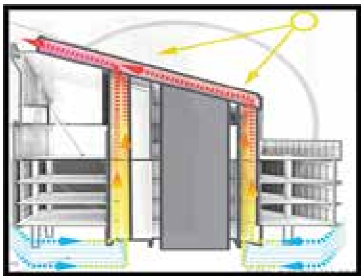
  B)Cupola: Cupola with an open hole on top works as an air sucking engine and in collaboration with the Wind-Tower, could create more air flow inside the space. It could also have positive effects during nighttime radiation. [Fig-8]



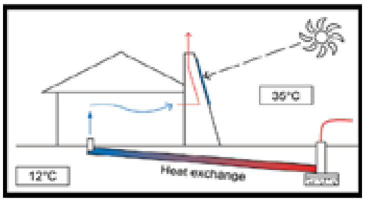
[Fig-8] Left: Cupola and Twin Wind-Towers in Shotor-Galu Building in Mahan, Iran

- **Horizontal Solar Chimney:** Horizontal Solar Chimneys on top of the roof could push out the warm air out of the building. In this way, it could also increase the air flow from down to up. [Fig-9]

- **Vertical Solar Chimney Effect of Exhausting Warm Air:** Vertical solar chimneys could lead warm air out, and in this way, the air flow from down to up or to other sides increases. [Fig-10]



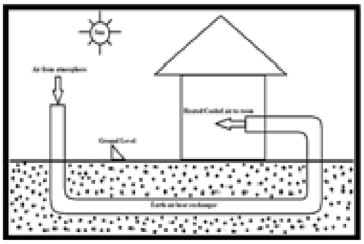
[Fig-9] Horizontal Solar Chimney Effect



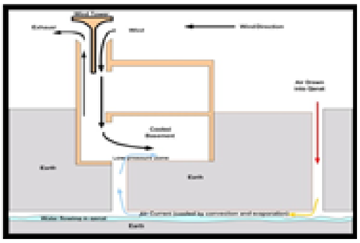
[Fig-10] Hybrid Working With Vertical Solar Chimney and Underground Thermal Mass

- **Underground Cool Temperatures (Underground Cool Thermal Mass):** Underground levels have a fixed temperature, and in combination with other passive strategies, could have an important effect on the decrease in air temperature. [Fig-11]
- **Underground Water Resources and Cool Temperature (Thermal Mass)**:Underground water resources could also help to decrease air temperature. [Fig-12]

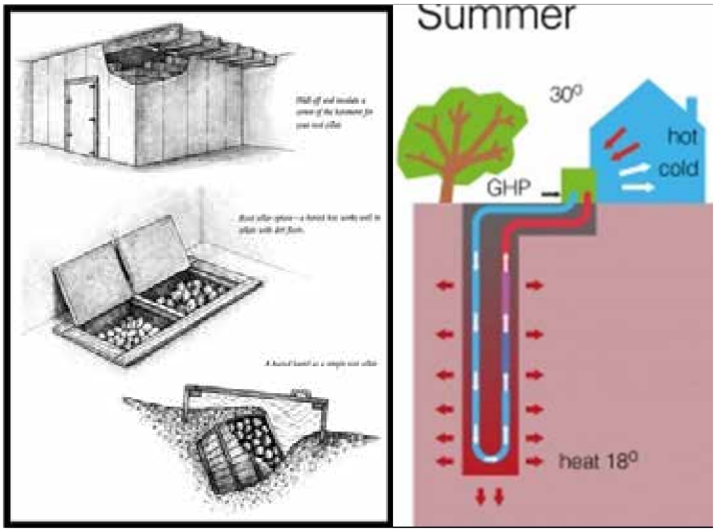
- **Underground Cold-Room (Root Cellar):** One of the common passive cooling strategies that is used in many parts of the world is the Underground Cold-Room, where the temperature is cooler than outside and food and agricultural products could be conserved for a longer period of time. [Fig-13]
  In traditional Iranian architecture, underground spaces have often been used for food conservation. They would hang the food on top of a wooden grid near the aperture under the Wind-Tower. In addition, the underground wind circulating under the Wind-Tower keeps the food dry. This dry air, along with the general lower temperature, thereby helps prevent the food from spoiling sooner than in other room temperature conditions. [Fig-14]



[Fig-11]



[Fig-12]



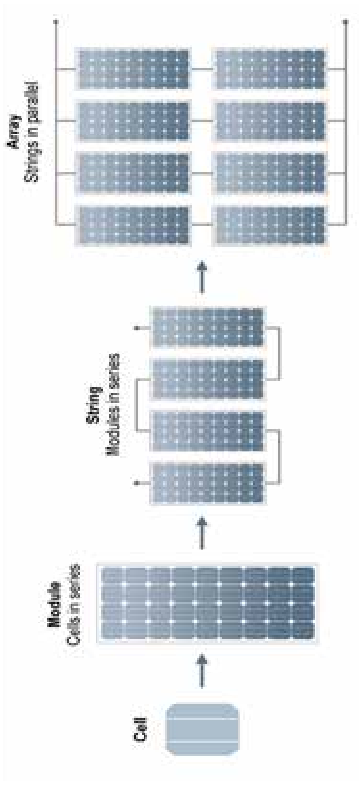
[Fig-13] Left: Root Cellar; Right: Underground Space with 18°C Fixed Temperatures

- **Photovoltaic Panel:** When there is a lack of electricity, Photovoltaic cells could be one of the best solutions in many developing countries, as a self-sufficient power station. It could also be more effective because of the high levels of annual sunny days in these areas. [Fig-15]

8.3.6 Question N.6: How can an architectural package be created that could build a small sized school and also have a refrigerator available for the conservation of farm products?

To answer this question, we need to first analyze and understand the relationship between education and food security.

[Fig-14] Underground Floor in a Traditional Persian Antique House (Wooden Grid to Hang on Top) (Photo by: Amir Imani)



[Fig-15] Module for Photovoltaic Panels

8.4 Physical Program

After thinking about the relationship between the farm and school system, we found that if we add another place in the school, we could create a new possibility for the storage of farm products in its Refrigerator Cellar. In this way, the circle of service and consumer, between School and Farmer could work perfectly together. [Fig-16]
In this project, the school is not just functioning as a traditional normal school. It will also be converted into a hybrid place that could offer more than just a normal education, but also provide a new service for food security. The school will not ask any money for this service (for storage of farm products in its refrigerator cellar), but instead, it will request for some percentage of the amount of storage products for a certain period of time. [Fig-17] Those farm products will be given to the children who study in the school.

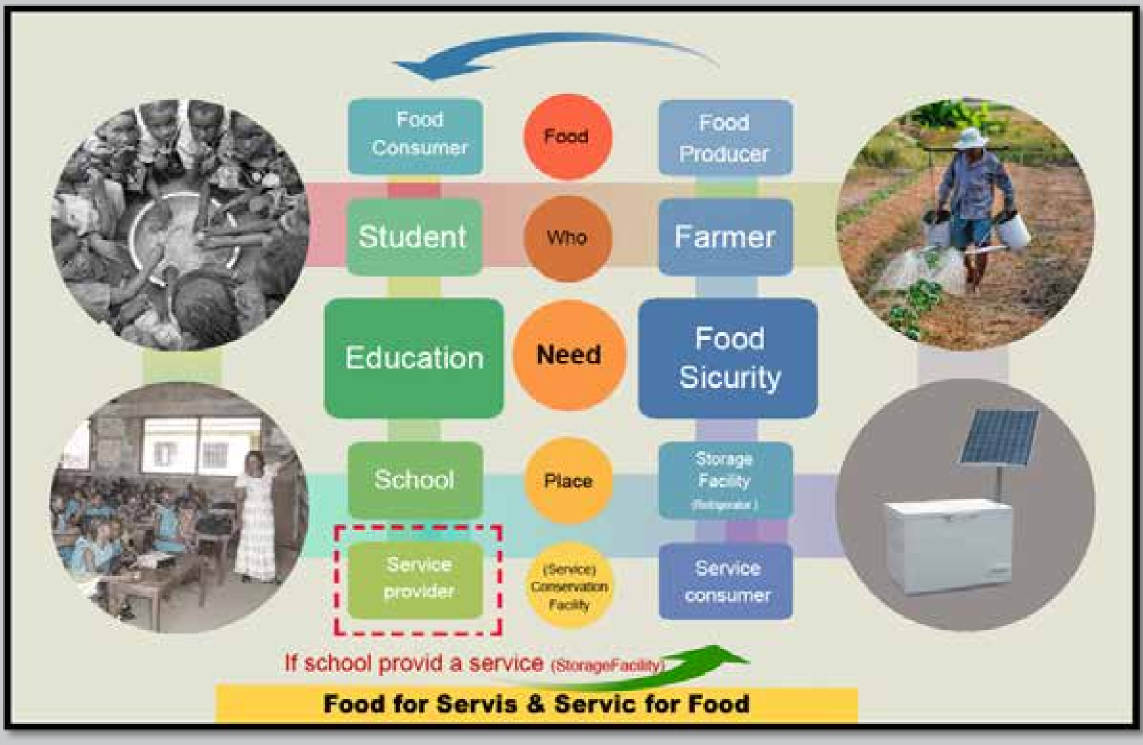
This new definition for schools will have three important functions aimed at resolving developing countries' problems outlined below.

- 1. Education ……………………………………..(Low education levels)
- 2. Help food security……………..……………………..(Low food levels)
- 3. Help the farmer to earn more mo…………..(Low income levels)

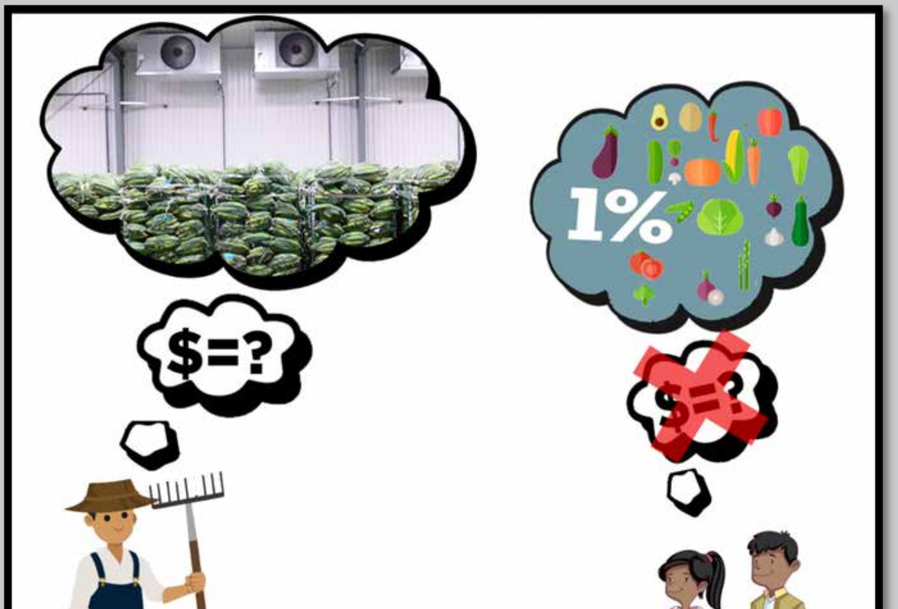
With a sustainable passive cooling system in its design, there could be a higher value to this project and we can create a better thermal condition along with a near zero energy school.

8.4.1 Question N.7: How could we make the project more practical and send it to several different places with hot climates, through the use of passive cooling systems in its architecture?

It was a challenge to create a passive cooling architecture system with natural ventilation that could be ubiquitously useful with low construction costs, and that has the possibility of being mobile (able to be transported it to other locations). The concept of transportation and low-cost leads to the idea of a container. The refrigeration aspect is also useful. [Fig-18]



[Fig-16] Diagram of the Relationship Between Food the Consumer and Producer, Food Security and Education (Copyright: Amir Imani)



[Fig-17] Food for Conservation

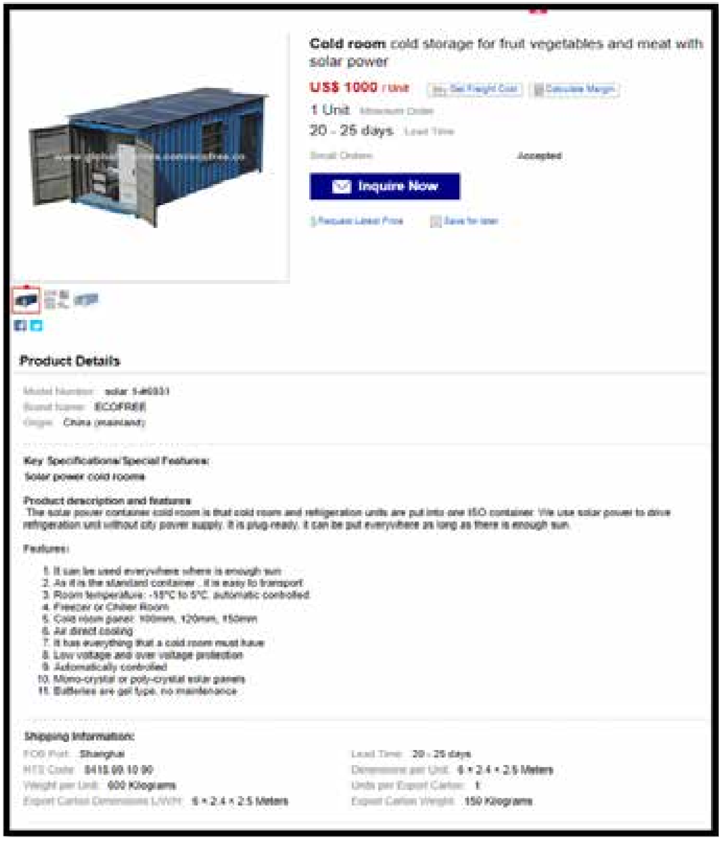
[Fig-18] *Transportation with Truck-Refrigerators*

8.4.2 Solar Container Examples

I began to research new projects that were recently created with these key words: Container, School, Refrigerator and Solar Photovoltaic Panel. I found interesting projects but noticed that more than having photovoltaic panels, they did not have characteristics of passive cooling architecture. In [Fig-19], we can see a solar powered internet school, which was a recent project from Samsung. [Fig-20] demonstrates a real example of a Solar cold room for food conservation (Sun Cooler Company). In [Fig-21], we can also see a solar cold room container with the cost of $1,000.

[Fig-19] Samsung Solar Powered Internet Shipping Container School

[Fig-20] Solar Refrigerator (Sun-Cooler Company)



[Fig-21] Solar Cold Room Made in China

8.4.3 Sustainable Low-Cost Architecture in Hot-Climate Areas That Used Natural Ventilation in Their Projects (Case Study C)

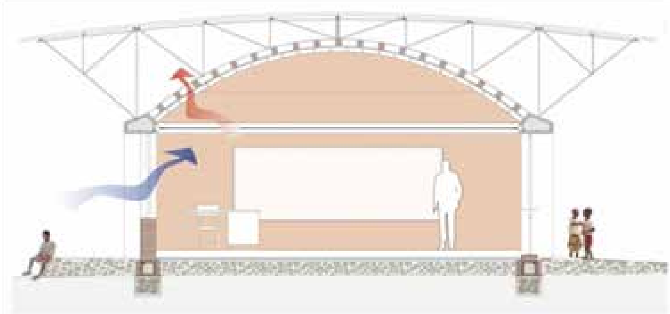
After all the research on solar-containers was completed, I started to study sustainable low-cost schools in hot-climate areas. There were many projects and case studies, but I would like to briefly present some interesting projects.

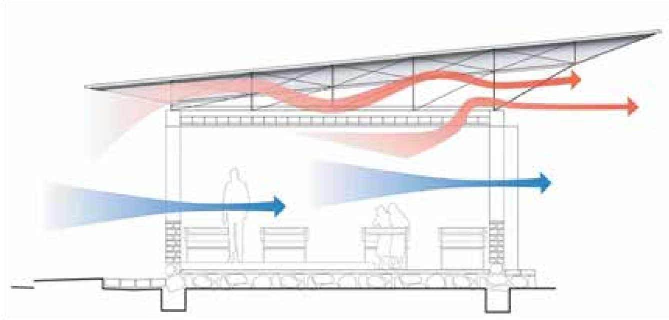
Case 1: Primary School in Burkina Faso (Francis Kéré)
[Fig-22]
"Context:
As a native of Burkina Faso, Diébédo Francis Kéré grew up with many challenges and few resources. When he was a child, he travelled nearly 40 km to the next village in order to attend a school with poor lighting and ventilation. The experience of trying to learn in this oppressive environment affected him so much that when he began to study architecture in Europe, he decided to reinvest his knowledge towards building a new school in his home village. With the support of his community and funds raised through his foundation, Schulbausteine für Gando e.V. (Bricks for Gando, now Kéré Foundation e.V.) Francis began the construction of the Primary School, his very first building.

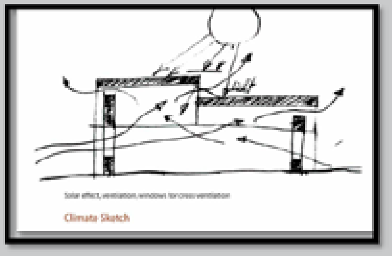
Compressed Earth-Blocs:
The design for the Primary School evolved from a lengthy list of parameters including cost, climate, resource availability, and construction feasibility. The success of the project relied on both embracing and negating these constraints. In order to maximize results with the minimal resources available, a clay/mud hybrid construction was primarily used. Clay is abundantly available in the region, and is traditionally used in the construction of housing. These traditional clay-building techniques were modified and modernized in order to create a more structurally robust construction in the form of bricks. The clay bricks have the added advantage of being cheap, easy to produce, and they also provide thermal protection against the hot climate.

Flying Roof and Air-Circulation:
However, despite their durability the walls must still be protected from damaging rains with a large overhanging tin roof. Many houses in Burkina Faso have corrugated metal roofs which absorb the

[1] “Awarded Architecture.” *Kere Foundation.* 2018. http://kere-foundation.com/en/philosophy/architecture







[Fig-22] Primary School in Africa, Architect: Francis Kéré; Top: Natural Ventilation Strategies

heat from the sun, making the interior living space intolerably hot. The roof of the Primary School was pulled away from the learning space of the interior though, and a perforated clay ceiling with ample ventilation was introduced. This dry-stacked brick ceiling allows for maximum ventilation, pulling cool air in from the interior windows and releasing hot air out through the perforated ceiling. In turn, the ecological footprint of the school is vastly reduced by alleviating the need for air-conditioning.

Participation of the Community:

Although the plans for the Primary School were drawn by Francis, the success of the project can be attributed to the close involvement of the Gando inhabitants. Traditionally, members of a whole village community work together to build and repair homes in rural Burkina Faso. In keeping with this cultural practice, low-tech and sustainable techniques were developed and improved so that everyone in Gando could participate in the process. Children gathered stones for the school foundation and women brought water for the brick manufacturing. This way, traditional building techniques were used alongside modern engineering methods in order to produce the best quality building solution while simplifying construction and maintenance for the workers." [1]

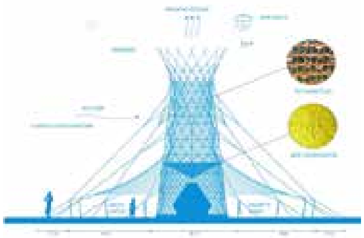
Case 2: ECO-HOUSES: SINA Village, Uganda

With construction and material costs skyrocketing at unbearable levels, unique ideas and applications have come up. This is especially true in third world countries where everything from money, supplies and resources are scarce. Take a look at these photos shared to us via Homes for You. Imagine the savings in cement, mortar and bricks because a lot of empty glass bottles were used in the walls. [Fig-23]

Think also of the energy savings during the day because light passes through them. And if planned ahead you can even arrange bottles of the same colors or mixed colors to illuminate the rooms. This idea has come of age in difficult times like this. The greatest thing is: it is already there. They are just ready for the taking from recycling centers. We are on top of a beautiful hill in a very peaceful environment! Since we are on a hill (and surrounded by hills) mountain bike rentals are possible, as well as kite rentals. Board games, football, volleyball and Frisbee are provided for free. We are 6km away from Mpanga Forest Eco Tourism Site and 40 Km to the Equator line.

[Fig-23] SINA Village is Located at the Social Innovation Academy (SINA)

[Fig-24] SINA Village, Sustainable Architecture Created a Job Opportunity



[Fig-26] Vittori Hopes to Build Several Towers in Ethiopia and is Hoping to Find Financial Backers Who Also Believe That Safe-Water Harvesting Is a Right that Should Be Afforded to Everyone

Case 3: Warka Water/ Architecture and Vision - Arturo Vittori

Warka Water/ Architecture and Vision - Arturo Vittori
Architects: Architecture and Vision
Country: Ethiopia
Project Team: Arturo Vittori and Andreas Vogler
Project Year: 2012
Photographer: Architecture and Vision
Website: www.architectureandvision.com
26 May, 2015 – Kililo Mtamu Research Centres Contemporary African Directory Centres Sustainability [Fig-25]
Throughout many remote villages in Ethiopia, water gathering is quite an arduous and dangerous task. With the burden typically falling on matriarchs of the family, the trip to the nearest water source can take hours if not all day. More often than not, that water fetched on these long journeys is commonly contaminated with dangerous elements such as human and animal waste. Additionally, many women have little choice but to bring their young children along, which not only puts them in harm's way, but also keeps them out of school.

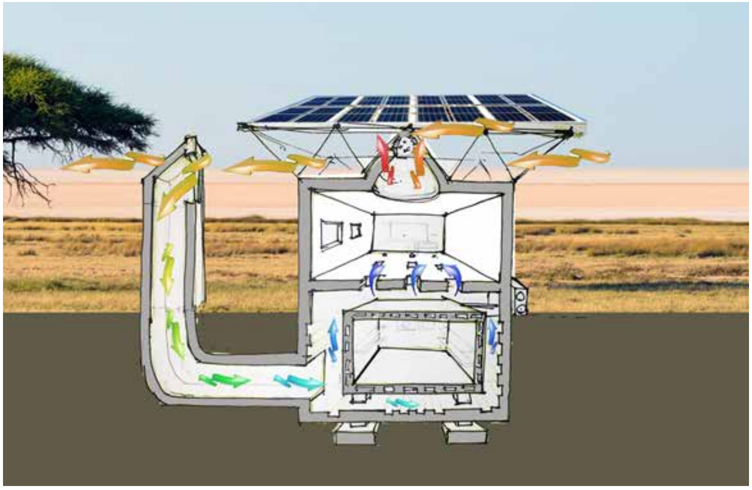
The WarkaWater Towers were inspired by the local Warka tree, a large fig tree native to Ethiopia that is commonly used as a community gathering space. The large 30 foot, 88 pound structures are made out of juncus stalks or bamboo woven together to form the tower's vase-like frame. Inside, a plastic mesh material made of nylon and polypropylene fibers act as micro tunnels for daily condensation. As droplets form, they flow along the mesh pattern into the basin at the base of the towers. By harvesting atmospheric water vapor in this way, it's estimated that at least 25 gallons of potable water can be sustainably and hygienically collected by the towers every day.
"WarkaWater is designed to provide clean water as well as ensure long-term environmental, financial and social sustainability," says the Architect. "Once locals have the necessary know how, they will be able to teach other villages and communities to build the WarkaWater towers." Each tower costs approximately $550 and can be built in under a week with a four-person team and locally available materials. [2] *Utilizing this innovation and involving the local people with the construction of their building will also give them a sense of belonging to this particular place."*

[2] "Warka Water/ Architecture and Vision - Arturo Vittori." *Archi Datum Architecture in Africa*. 2015. www.archidatum.com/projects/warka-water-architecture-and-vision-arturo-vittori/

8.5 Sustainable Project HB-WT

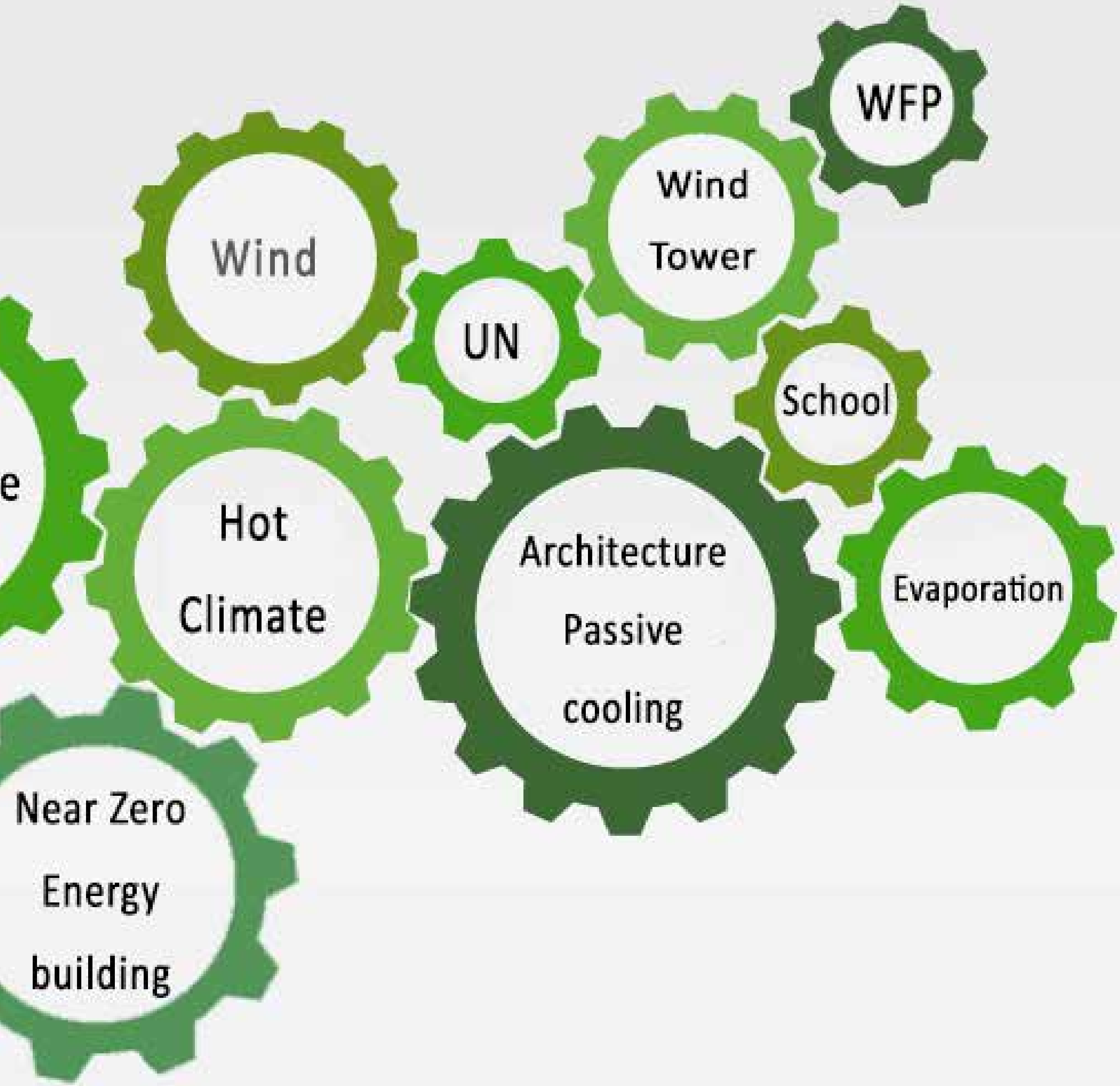
8.5.1 School

We will not spend any electricity energy for cooling schools.
Passive Cooling and Natural Ventilation and Thermal Mass:
By using a hybrid passive cooling system, the classrooms can be more efficiently cooled using natural ventilation. One or two Wind-Towers will capture the local favorable winds, direct it to the underground duct, which is connected to the underground floor (where the refrigerator cellar will be located). By passing between the underground duct and underground floor, the air will lose its high temperature and become cooler. The small sized apertures that are located on the classroom floors inside, in the end, will exit from the two cupolas where they are located – one being the roof under the solar photovoltaic panels.
In the underground duct, water-bottles were added, thus they could store the cold temperature from night ventilation for a longer time. [Fig-27]



[Fig-27] Diagram of Passive Cooling Strategies by Thermal Mass and Natural Ventilation

Global Warming
Poverty
Food Conservation
Architectur
Human Comfort
FAO
Hunger
Sustainable
Hunger



WFP
Wind
Tower
Wind
UN
School
e
Hot
Climate
Architecture
Passive
cooling
Evaporation
Near Zero
Energy
building

8.5.2 Refrigerator Cellar

The refrigerator will be located on the underground floor where the temperature is constantly at around 23°C. This means the thermal difference between outside the refrigerator and inside is 23°C - 5°C = 18°C. The refrigerator engine needs to produce energy to make it cool 18 °C, otherwise if the fridge was not underground and had an on the ground position where it was over 40° C, it would need to produce energy to cool 35°C (40°C - 5°C = 35 °C.). The electricity power for these refrigerators will be produced by solar photovoltaic panels.

8.5.3 Photovoltaic Panel

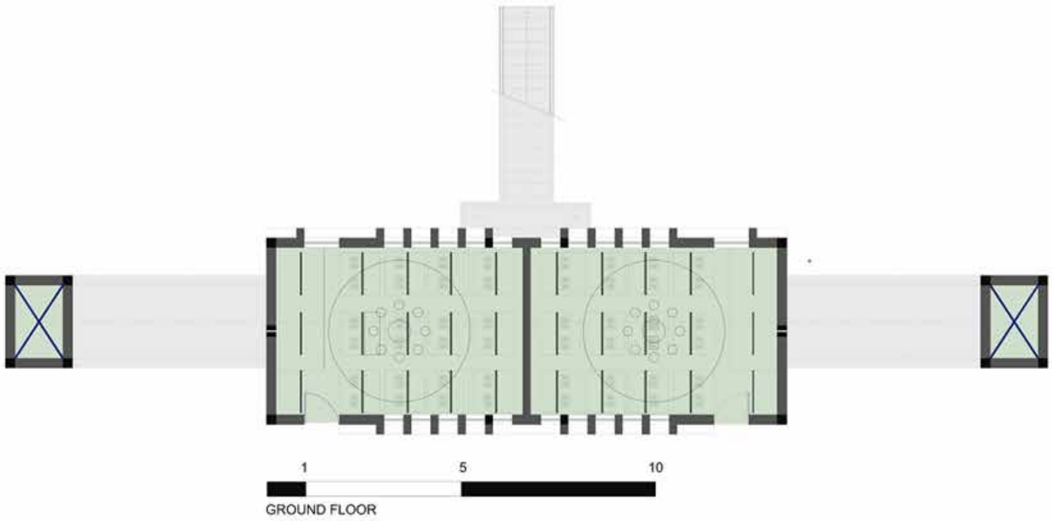
They were designed to:

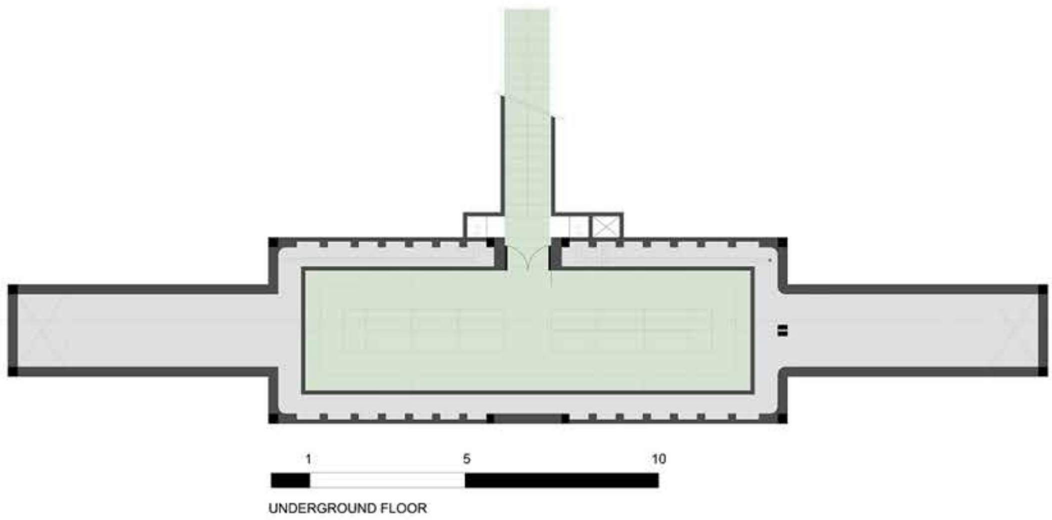
- Make more shade on the school walls
- Help to pass air over the cupola and create a vacuumed Venturi effect on top of the cupola that increases its efficiency
- Produce the electricity for school and fridge

8.5.4 Underground Duct

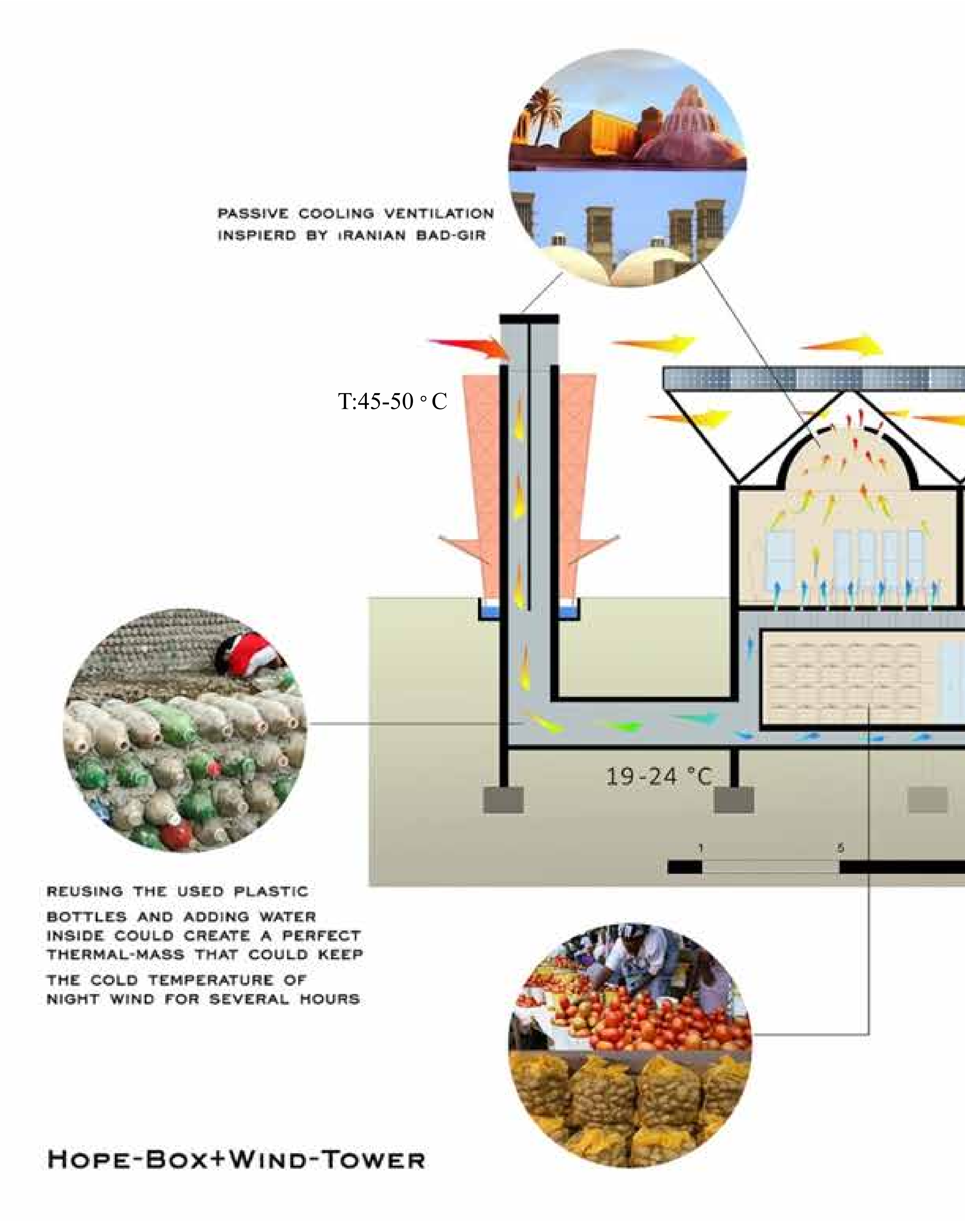
The underground duct made from bottles of water, which could conserve the cold nighttime temperature of nighttime ventilation for more hours. Thus, when the wind passes inside the underground duct, it will lose some of its temperature.

8.5.5 Plan

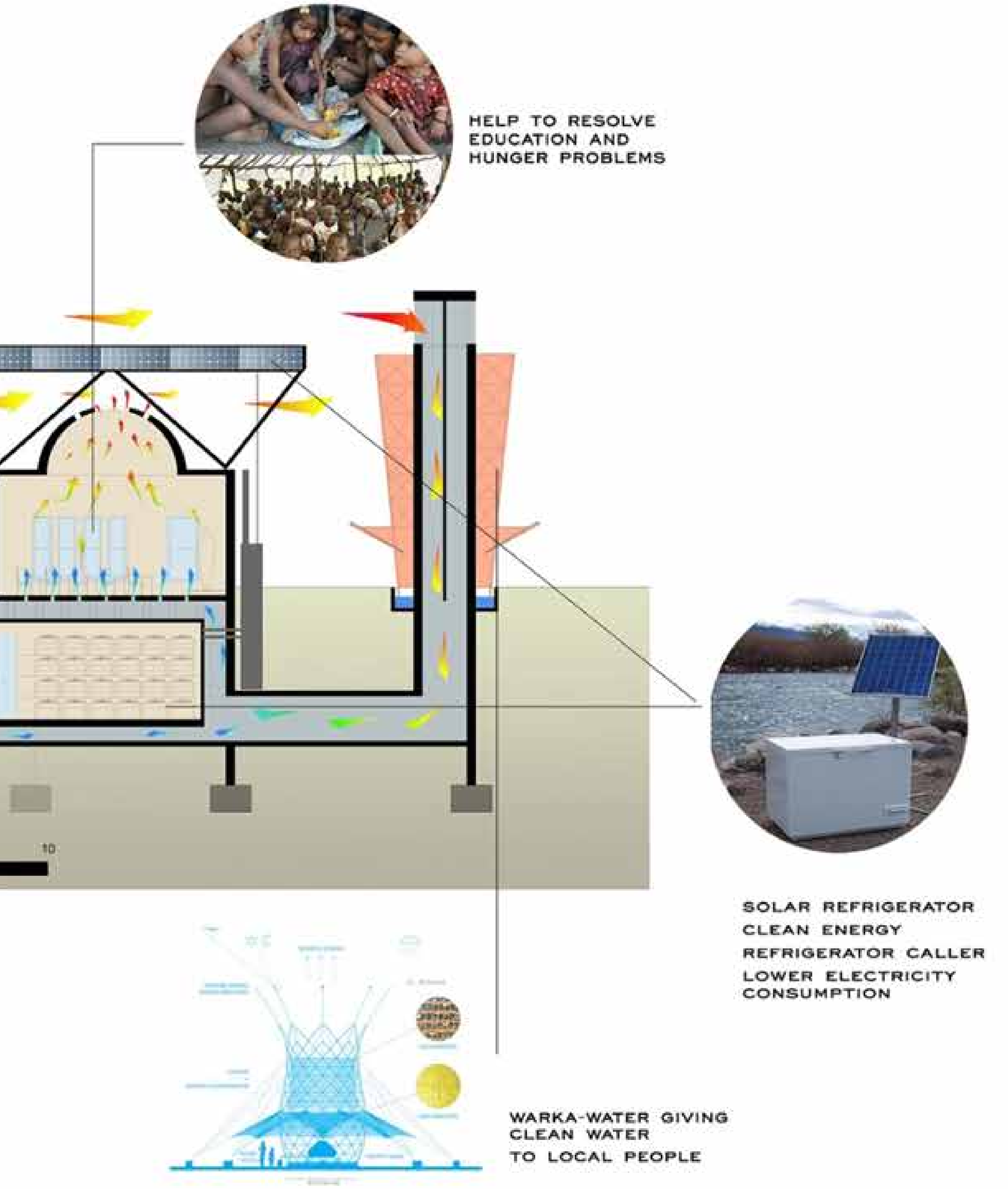




8.5.8 Section



PASSIVE COOLING VENTILATION
INSPIERD BY IRANIAN BAD-GIR
T:45-50 ° C
19-24 °C
REUSING THE USED PLASTIC
BOTTLES AND ADDING WATER
INSIDE COULD CREATE A PERFECT
THERMAL-MASS THAT COULD KEEP
THE COLD TEMPERATURE OF
NIGHT WIND FOR SEVERAL HOURS
HOPE-BOX+WIND-TOWER


HELP TO RESOLVE
EDUCATION AND
HUNGER PROBLEMS
10
SOLAR REFRIGERATOR
CLEAN ENERGY
REFRIGERATOR CALLER
LOWER ELECTRICITY
CONSUMPTION
WARKA-WATER GIVING
CLEAN WATER
TO LOCAL PEOPLE

8.6 Conclusion

- When students have a better thermal condition in their school, they have more motivation to come and spend more time inside the classroom.

- They know if they come to school, there will be a strong possibility of receiving some fruits or other food products from the farmer who had conserved them in the school refrigerator cellar. Thus, children have more of an incentive to come to school if they will be fed.

- These refrigerated cellars could also benefit humanitarian agencies, such as WFP, as they could provide convenient and low cost facilities to store food for school-feedings and other distribution efforts and programs that benefit food insecure populations.

- Hunger will kill hope in children and will cause many psychological issues in addition to physical ones. When they know that underneath their classroom lies large amounts of food, mentally and psychologically, they could be more motivated for life and have a little more of an optimistic vision of their future.

- By using natural cooling ventilation and thermal mass, the electric consumption of the refrigerator decreases by half, consequently, we could use this electricity for other daily needs of the local community.

- The Wind-Tower, underground duct and exterior walls of the school could be built and painted by local people. In this way, they could participate in the construction process and feel more involved in their community.

- Hop-Box+Wind-Tower is a flexible product. It could change its application depending on the needs of the area and people and it could be updated to adapt to different microclimates.

- In cases of emergencies like earthquakes or floods, the Hop-Box+Wind-Tower could provide more thermal comfort for people who particularly have been directly afflicted, and it could also be easily transported by trucks to other places.

8.7 Other Considerations and Reflections

- The reality is that every place on earth is affected by a variety of climatic conditions. Thus, in order to develop a more practical project, we must conduct a more comprehensive study of the microclimate, quality and quantity of the local winds, and the project would then have to be updated, reflecting these new situations.
- Many developing countries are often times most adversely affected by extreme climates, and thus sustainable and cost-effective solutions are needed. However, these solutions cannot be implemented without the proper investments and policies of their respective governments and help of international organizations.
- One solution could be the establishment of new programs that teach low-cost bioclimatic architecture directly to the local communities that are affected by these extreme climates.
- An important consideration is the fast-moving pace of technology and science, which progresses every single day, uncovering new discoveries and expanding our knowledge. Therefore, the contents of this study could have new additions.
- The study of ancient bioclimatic architecture could also have a quantitative analysis, but it is important to have an expanded vision in order to control all effective elements, and this requires long term collection of data and monitoring etc. In many studies that took place in this field, the researchers had analyzed one or two effective factors, but not all together.
- In this study, the main target was to propose major low-cost passive cooling strategies of bioclimatic architecture to facilitate the daily life of ordinary people in developing countries living in hot climates, and introduce a realistic innovative project based on all of the information in this study. These recurring low costs can then stimulate one-off investments in more construction of these structures, and this will promote greater usage over time.

In the hopes of a better world, with a cleaner and cooler environment, more happiness, and less poverty and hunger.

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